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# MINUTES OF PROCEEDINGS

OF

# THE INSTITUTION

OF

# CIVIL ENGINEERS;

WITH

## ABSTRACTS OF THE DISCUSSIONS.

## VOL. XXXVI.

SESSION 1872-73.—PART II.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

INDEX, PAGE 354.

7765

LONDON:
Published by the Institution,
25, GREAT GEORGE STREET, WESTMINSTER, S.W.
1873.

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THE

# INSTITUTION

OF

# CIVIL ENGINEERS.

SESSION 1872-73.—Part II.

March 25, 1873.

T. HAWKSLEY, President,
in the Chair.

## No. 1,340.—"The Mont Cenis Tunnel." By Thomas Sopwith, Jun., M. Inst. C.E.[1]

In the beginning of 1864, the Author submitted to this Institution a Paper upon "The Actual State of the Works on the Mont Cenis Tunnel, and Description of the Machinery employed,"[2] in which he gave the information he had been able to obtain, during two visits to the works, in the autumn of 1860, and the summer of 1863, respectively. At the latter date, although the works had been in progress since the end of 1857, about $5\frac{1}{2}$ years, only 2,542 mètres of gallery had been pierced, or about $\frac{1}{5}$th of the total length. At the end of 1870, $7\frac{1}{2}$ years afterwards, the entire distance had been traversed.

The Author again visited the tunnel in November, 1871, when it had been for some months open to traffic; and in the present communication, which is offered as supplementary to his former Paper, will describe:—

1. The tunnel as completed, with statistics obtained either by actual observation, or from the Engineers in charge, or from official publications of the Italian Government.

[1] The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xxiii., p. 258.

2. The principal changes which have been introduced in the works and machinery, underground and 'at surface,' since the summer of 1863.

## I.—The Tunnel as Completed.

On Dec. 25, 1870, at 4·25 P.M., the machine perforator No. 45, working on the Bardonnèche, or Italian side, knocked a bore-hole, 3·80 mètres long, and 5 centimètres diameter, through the diaphragm of rock then separating the advanced galleries from Italy and from France. The information was telegraphed to Turin, and a special train left early the following morning, conveying the contractors, Engineers, and their friends to Bardonnèche. A number of bore-holes were in the meantime bored in the curtain, or diaphragm, of rock. These being fired, the advanced galleries were brought into communication on Dec. 26, 1870, at 5·20 P.M. (Italian time), and Mr. Copello, the Engineer in charge of the works on the French side, passed from end to end of the tunnel, entering at Modane, and coming out at Bardonnèche.

There was an error of only 1 ft. in the calculation of the Engineers as regards the level at the meeting of the two galleries, the Modane gallery being the higher. In the direction there was no error.

The actual length of the tunnel proved to be more than had been estimated. Some anxiety was in consequence felt in the last few days previous to the communication being effected, as it was feared the ends had overlapped. It was found that the actual length of the tunnel, between the extremities, was 12,233·55 mètres (7·6017 miles), instead of 12,220 mètres (7·5932 miles). The difference being 15 yards. The following figures should also be substituted for those formerly stated by the Author :—

| | | |
|---|---|---|
| Modane, or north entrance, is . . . | 3,801 | ft. above level of sea. |
| Bardonnèche, or south entrance . . | 4,236 | „ „ |
| Summit of tunnel . . . . . | 4,246 | „ „ |
| „ section . . . . . | 9,527 | „ „ |

The gradient of the tunnel has also been altered, though not to a material extent.

The railway does not enter at the extremities of the tunnel, but there is a curved line at the Modane end, on the east side of the tunnel, 496 yards long, with a gradient of 1 in 43½, which joins the tunnel 378 yards from the north extremity ; and at Bardonnèche a similar line on the west side, 827¾ yards long, with a gradient of 1 in 33, which joins the tunnel 274¾ yards from the

south extremity. The total length of tunnel traversed by the trains is, therefore, 12,846·92 mètres (7·9806 miles).

Geological formation.—In the total length of the tunnel (12,233·55 mètres) the following different sorts of rock were traversed :—

| | Mètres. |
|---|---|
| Carbonaceous schist | 2,096·50 |
| Quartz | 388·50 |
| Limestone and dolomitic limestone | 355·60 |
| Calcareous schist | 9,392·95 |
| Mètres | 12,233·55 |

The above statement shows the order in which the rocks were met with, going from Modane to Bardonnèche, and is another substantial proof of the accuracy with which the preliminary studies were made by the Commissioners appointed by the Italian Government; coinciding as they do so nearly with the previous estimates made—the most considerable variation being fortunately in the thickness of quartz to be pierced, which had been estimated at 537 mètres.

Ventilation of the tunnel, &c.—It was expected that, on the completion of the tunnel, the difference of level, amounting to 435 ft., between the French extremity and the Italian extremity would have insured a steady current of fresh air from north to south, in all states of the weather, and under any probable amount of circulation of traffic. This has not been found to be the case. The ventilation is far from good; not bad enough seriously to incommode passengers, or to impede the present limited amount of traffic, but bad enough to render the work of the watchmen, rail-layers, and others employed in the tunnel insupportable at times, and to cause apprehensions that, with increased traffic, serious difficulty in working the line would be experienced. A remedy is now being applied—and will shortly be completed—by laying a pipe of 20 centimètres, or 8 in. diameter, from end to end of the tunnel, midway between the two lines of rails, which will be supplied with compressed air by a pair of 'compresseurs à pompe,' worked by a water-wheel at the Italian end. This pipe will have cocks at short intervals, to be opened as occasion may require by the men at work in the tunnel.

The tunnel since it has been open for traffic has been lighted by oil-lamps, one of which is placed at each 500 mètres; every

alternate one is marked legibly with the distance, in kilomètres, from the Bardonnèche entrance. At each 1,000 mètres there is a lamp-room, 3 mètres square. Shelter-places, or niches, 1·5 mètre broad by 1 mètre deep, are provided alternately on the two sides of the tunnel, at distances of 50 mètres from the Bardonnèche end, and at distances of 25 mètres from the Modane end.

Masonry.—The tunnel is walled, with the exception of about 300 yards on the French side. The side walls are stone, 8 ft. 6 in. high throughout. The arch on the Italian side is principally constructed of brick, and on the French side of stone, a brick key being used throughout. There are good side-paths of flagged stones, about 1 ft. 8 in. broad. The walling and brickwork are executed substantially, and with remarkable uniformity, considering they were not commenced and carried straight forward, but in sections at several different points at the same time. It was found impossible otherwise to keep pace with the progress of the advanced galleries.

Temperature.—In the preliminary stages, and during the first few years of work in the tunnel, no point perhaps excited more attention and interest than the probable heat which would be found under a vertical section of so much as 5,281 ft., or 1 mile.

In England, the deepest mines have not a depth of $\frac{1}{2}$ mile, and the experiments made in them are less interesting than if made at a similar depth, removed from mineral deposits, which in many cases, when in contact with air, increase the temperature by slow chemical decomposition. From observations taken in England and elsewhere, it has been found that there is an increase of temperature of from $1\frac{1}{2}°$ Fahrenheit to $2\frac{1}{2}°$ Fahrenheit in each successive 100 ft. in depth, commencing at the level of the sea. Assuming, for the moment, that the conditions as to temperature at Mont Cenis are not materially altered by its elevation above sea level, and taking a mean of 2° Fahrenheit as the increase of temperature due to each 100 ft., the temperature in the tunnel should be 100° Fahrenheit higher than what would be observed at the bottom of a pit sunk from the summit of the section to a depth of about 80 ft.

The Author prefers to state the case so, rather than to date the increase of temperature from the mean temperature at the surface of the summit; and he believes the mean temperature observed in such a pit, at a depth unaffected by atmospheric changes, would be not less than 50° Fahrenheit, or 60° Fahrenheit. If these

premises are correct, then in the middle of the tunnel the temperature should have been 150° Fahrenheit or 160° Fahrenheit. It will be remembered that the investigations of the Coal Commission appointed by the British Government were to the effect that, at a depth of 4,000 ft. from the surface, the temperature would be so great as to prevent the economical working of coal.

The temperature in the tunnel was, however, found to be less than was anticipated, for, at a distance of 7,000 mètres from the Bardonnèche entrance, a spring was found, the temperature of which was 84° Fahrenheit. This temperature corresponded with observations previously taken in bore-holes driven from the sides of the tunnel. The section at this point shows a thickness of rock above of 5,084 ft. (nearly 1 mile); and, calculating at the rate of 12 cubic feet to the ton, there is a pressure due of 422 tons per square foot. The elevation above the level of the sea, and the form of the mountain—which allows more radiation to take place—may be the causes of so low a temperature, in comparison with what might be expected at a similar depth from the surface, if reached from a level plain.

The following extracts were made by the Author from the observations kept at Bardonnèche, the centigrade numeration being converted into Fahrenheit:—

| Distances from the Bardonnèche Entrance. | Works in Progress. | | Advanced Gallery Completed. |
|---|---|---|---|
| | January 16th, 1869. | April 17th, 1869. | May 20th, 1871. |
| Mètres. | Fahrenheit. ° | Fahrenheit. ° | Fahrenheit. ° |
| 0 | 32 | 42 | .. |
| 500 | 45½ | 48½ | 74½ |
| 1,000 | 50 | 53 | 75 |
| 1,500 | 54 | 57 | 76½ |
| 2,000 | 58½ | 60½ | 77 |
| 2,500 | 61½ | 63 | 78 |
| 3,000 | 64½ | 66 | 79 |
| 3,500 | 67½ | 68 | 79 |
| 4,000 | 70 | 70 | 80 |
| 4,500 | 71½ | 71 | 80 |
| 5,000 | .. | .. | 80 |
| 5,500 | .. | .. | 80 |
| 6,000 | .. | .. | 80 |
| First enlargement by manual labour | 86½ | 85½ | .. |
| Second enlargement by manual labour | 86 | 87 | .. |

The observations of temperature taken during the progress of the works, though of little scientific value, are not without

interest now that similar undertakings are in contemplation. The temperature varied considerably, according to the number of men employed and the quantity of gunpowder consumed, and reached its maximum at the places where the enlargements of the advanced galleries, to full tunnel size, were being made. It must be remembered that cocks were opened in the supply-pipe of compressed air at intervals. By opening these cocks the air was reduced in their immediate neighbourhood to freezing point; otherwise the temperature would have been much higher during the progress of the works.

Since the completion of the tunnel, the temperature of the air in the middle has varied from 80° Fahrenheit to 90° Fahrenheit. With a slow current of air, the vapour from the engine, with full steam up, when mounting from the north end, advances slowly and fills the tunnel, though inside the carriages, it is not inconvenient.

Rate of progress effected, and duration of works.—The following table gives the distances executed in the advanced galleries from each end:—

| | | Bardonnèche. | | Modane. | | Total. | |
|---|---|---|---|---|---|---|---|
| | | Mètres. | Mètres. | Mètres. | Mètres. | Mètres. | Mètres. |
| By hand labour | 1857 | 27·28 | | 10·80 | | 38·08 | |
| ,, ,, | 1858 | 257·57 | | 201·95 | | 459·52 | |
| ,, ,, | 1859 | 236·35 | | 132·75 | | 369·10 | |
| ,, ,, | 1860 | 203·80 | | 139·50 | | 343·30 | |
| ,, ,, | 1861 | Nil. | | 193·00 | | 193·00 | |
| ,, ,, | 1862 | Nil. | | 243·00 | | 243·00 | |
| | | | 725·00 | | 921·00 | | 1,646·00 |
| By machine . | 1861 | 170·00 | | .. .. | | 170·00 | |
| ,, | 1862 | 380·00 | | .. .. | | 380·00 | |
| ,, | 1863 | 426·00 | | 376·00 | | 802·00 | |
| ,, | 1864 | 621·20 | | 466·65 | | 1,087·85 | |
| ,, | 1865 | 765·30 | | 458·40 | | 1,223·70 | |
| ,, | 1866 | 812·70 | | 212·29 | | 1,024·99 | |
| ,, | 1867 | 824·30 | | 687·81 | | 1,512·11 | |
| ,, | 1868 | 638·60 | | 681·55 | | 1,320·15 | |
| ,, | 1869 | 827·70 | | 603·75 | | 1,431·45 | |
| ,, | 1870 | 889·45 | 6,355·25 | 745·85 | 4,232·30 | 1,635·30 | 10,587·55 |
| Total Mètres . . | | | 7,080·25 | | 5,153·30 | | 12,233·55 |

The greatest progress made in the gallery in any one month was in May, 1865, when 399½ ft. were driven; and the least progress, after the successful application of the boring machines, was in April, 1866, when 35 ft. in the quartz were driven; both of these statements having reference to the Modane end.

On the whole, better progress has been made at the Italian end than at the French end of the tunnel, partly owing to the rocks being more favourable, and partly owing to the advanced gallery being carried forward on a smaller size.

Cost.—This is not yet known officially; it is supposed, however, to be about £3,000,000.

The Author in his previous Paper[1] gave a translation of the principal heads, omitting details, of an agreement entered into between France and Italy, on May 7, 1862, and also gave the following estimate of the probable amount which would be due from France to Italy, the Government of the latter country having undertaken the completion of the tunnel:—

"Supposing the works to be finished at the expiration of ten years, from January 1st, 1862, and that the length of gallery completed at the end of the first year is 800 mètres, with an addition of 590 mètres each succeeding year, then, at £120 per mètre, the simple interest paid by the French Government will have amounted, according to Article 5, to £207,200. The sums received by the Italian Government, according to Articles 5 and 7, for the execution of the works will then be—from France—

| | |
|---|---|
| "Price as per Article 4 . . . . . | £760,000 |
| 10 years' premium at £20,000, per Art. 4 . | 200,000 |
| 5 years' premium at £24,000, per Art. 4 . | 120,000 |
| Interest received during the ten years, per Art. 5 . . . . . | 207,200 |
| | £1,287,200 |
| Adding the sum, per Article 7, to be paid by the Victor Emmanuel Railway Company . | 520,000 |
| Total . . | £1,807,200 |

"The estimated cost of completing the tunnel is £2,600,000; so that, taking into account the value of machinery left on their hands, if the above estimate be true, and the works are brought to a close in ten years, the Italian Government will not have to buy the advantages of a railway into their territory very dear. It would appear, also, that the French Government would pay for that part of the tunnel situated in their property the sum of £1,287,200, which divided by 6,110 mètres (half the length of the tunnel) gives £210 as the rate per mètre."

If the conditions of the agreement have not been altered, the preceding estimate of £1,287,200 is about correct, and should

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxiii., p. 273 *et seq.*

represent approximately the amount to be received by Italy from France; to which adding £520,000 to be paid by the Victor Emmanuel Railway Company; and deducting the total £1,807,200 from the supposed cost, or £3,000,000, the cost to the Italian Government seems to have been £1,192,800, from which should be deducted the value of a large amount of plant, which it seems probable will be turned to useful account in the construction of other tunnels.

On Dec. 21, 1867, the Italian Government sublet to Messrs. Sommeiller and Grattoni the completion of the remainder of the tunnel, at the price of 4,617 francs (£184 5*s.* 6*d.*) per lineal mètre of completed tunnel. 4,386·90 mètres remained at that time to be pierced.

## II.—Changes introduced in the Conduct of the Works since 1864.

Ventilation.—In June, 1863, when 1,092·25 mètres had been driven on the north side, and 1,450 mètres on the south side, there were no means actually adopted for ventilation, further than the admission of compressed air, by means of cocks, from the supply-pipe, and the large quantity of air exhausted from the perforators in the fore-head of the advanced gallery.

In 1864, a brattice was placed from each entrance, dividing the tunnel horizontally, the fresh air passing along the under side to as far as the walling of the tunnel was completed, and returning along the upper side. At Bardonnèche the draft was stimulated by the return air being taken up in a conduit to a chimney, the top of which was not less than 300 ft. above the level of the tunnel; this being found insufficient, a large fan, about 32 ft. diameter, was used to exhaust this air, and it produced a strong draught and good ventilation. At the Modane end, however, owing to the gradient and the increasing height from which the vitiated air had to be extracted, and also owing to its high temperature, neither of the above measures were sufficient, and it was found necessary to apply powerful exhausting pumps. The difficulty of ventilation was greatly increased in 1869 and 1870, not only owing to the increased distances of the works from the entrances, but also to the greatly increased number of men it was found necessary to employ in enlarging the tunnel, to keep pace with the improved results and unprecedented rate of progress in the advanced gallery; up to the last, however, a sufficient and ample circulation of air was maintained.

Enlargement of the advanced gallery.—Hand labour was found insufficient for this work. Although it was carried on at several points simultaneously—as many as six at each end—it was found impossible to carry away the rock extracted from the advanced gallery, with so many blockages in the tunnel. At considerable increase of expense, so far as the actual enlargement was concerned, but with great gain in rapidity of advancement, the machine perforators were applied, in 1868, to this work, and the enlargement concentrated to one point, at each end.

Figs. 1—7 (Plate 9), show the successive operations in the enlargement of the gallery at the south side of the tunnel:—

Fig. 1. Advanced gallery, about 9 ft. 6 in. broad and 8 ft. 6 in. high, driven by machinery; 7 perforators being used.

Fig. 2. First enlargement by machinery of the advanced gallery to 12 ft. square; 5 perforators being used.

Fig. 3. Second enlargement by machinery of the advanced gallery to 18 ft. high; 2 perforators being used; the support, or 'affût,' being carried on rails, resting on timber framing in the gallery.

Fig. 4. Third enlargement of the advanced gallery in the top part to full size required by manual labour.

Fig. 5. The upper part of the tunnel secured with arching.

Fig. 6. The lower part of the tunnel enlarged to the full size required—a length of a few feet only being extended at a time, with supports, or pillars, left to sustain the arch, which were afterwards taken away.

Fig. 7. The tunnel completed.

The stage of the operations indicated by Fig. 5 is open to objection, but the system was probably the best that could have been adopted, inasmuch as it was of importance that the walling should be made as soon as possible, before the action of the air rendered the rock unsound. The masons obtained good foundations for the centres on the rock at each side, and the line of rails was left clear for the transport of the broken rock from the advanced gallery.

Alterations in machinery.—In the first few years that the works were carried on, the 'compresseur à colonne d'eau' was used at both ends of the tunnel, but its use was discontinued first at Modane, and afterwards, in 1865, at Bardonnèche, on account of the breakages being frequent, and the duty performed unsatisfactory.

The 'compresseur à pompe' was substituted, and continued to give excellent results up to the time of the conclusion of the

works. Both machines are described in detail in the Author's former Paper,[1] and no important changes have been introduced in the 'compresseur à pompe.'

At Modane the 'compresseur à colonne d'eau' was applied under very disadvantageous circumstances; for as there was no sufficient head of water available, water-wheels worked from the river were used to pump the water into a tank, placed at a height of 26 mètres, whence it went to work the 'compresseurs à colonne d'eau.' It was a favourite machine of M. Sommeiller, and he seems to have been opposed to its being replaced by the 'compresseur à pompe,' although he afterwards allowed that the latter machine was much superior.

Many alterations have been made in the details of the perforator since its first introduction, and also from the form described in the Author's former Paper. The principle which distinguishes it from other machines of a similar nature, namely, the employment of two distinct machines, the motor and the percussion cylinder, has, however, been retained throughout. The following changes have been made:—

The size of both cylinders has been increased.

An air-buffer at the back of the percussion cylinder has been introduced, with great advantage.

The strong spiral spring K (vol. xxiii., Plate 4[A]), for pushing forward the catches q', has been suppressed, and substituted in more recent machines by a new arrangement (Plate 10, Fig. 3, T); by which the air, acting on a small piston, performs the same office.

The rotation of the borer, formerly effected by the turning of a square arbor in the piston, is now performed at the end of the frame, near the face of the rock, where the torsion is much less.

The machine as a whole is better balanced, and the repairs required have considerably diminished of late years.

The principal dimensions of the perforator now in use are pretty nearly as follows:—

Motor or Rotary Engine.

| | |
|---|---|
| Diameter of piston | 2·638 in. |
| Area | 5·4556 square inches. |
| Effective pressure, deducting back pressure | 69 lbs. per square inch. |
| Length of stroke | 2·834 in. = ·236 ft. |

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxiii., p. 265 *et seq.*; and p. 276 *et seq.*

PERCUSSION CYLINDER.

| | |
|---|---|
| Diameter of piston | 3 in. |
| Area | 7·068 square inches. |
| Effective area, deducting annular space, or counter pressure | 4·374 „ „ |
| Average length of stroke | 8 in. = ·666 ft. |

Supposing the percussion machine to make 250 strokes per minute (or the rotary machine 250 revolutions per minute), the power developed is 1·35 H.P. in the rotary engine, and 2·46 H.P. in the percussion cylinder, and the quantity of compressed air amounts to 12·662 cubic feet per minute.

The Author has not obtained information as to the duty performed by the 'compresseur à pompe;' it is probable, however, the production of 12·662 cubic feet of air, compressed to 6 atmospheres, or 5 above atmosphere pressure, will require, with good machinery, about 14 H.P. The pressure 'at surface'—6 atmospheres—is reduced to 5·7 atmospheres in the middle of the tunnel. Neglecting the slightly increased pressure due to the heat of the compressed air, and taking atmosphere pressure at 14·7 lbs. — deducting 1 atmosphere for back pressure—the effective working pressure will be $4·7 \times 14·7 = 69$ lbs. per square inch.

The latest improvements indicated, but not yet tried on a large scale, in the Sommeiller perforator are, the Author considers, still more important than any previously introduced. A third cylinder will be introduced, which will keep the percussion cylinder up to its work, and withdraw it immediately when necessary to change a borer—an operation which now requires some minutes; and the whole of the complicated machinery—the clutch, worm-screw, &c. —will be suppressed.

As a mechanical question, it is interesting to consider whether the principle of Sommeiller's machine is correct in applying two machines, where most other inventors use but one. The Author is of opinion that it is. The compactness of the machine is, however, sacrificed, and a longer frame is also required than for other machine drills.

The illustrations of the perforator (Plate 10, Figs. 1, 2, and 3) are taken from a prize essay by Signor Pietro Fautrier, presented to the Italian Government School of Mines, and copied by him from the actual working drawings at the Bardonnèche workshops.

A A are the guides for the percussion cylinder, and they form the frame of the machine.

B is the cylinder of the horizontal engine fixed at the back of the frame.

C is the percussion cylinder, supported on the frame A A by shoulders, and it is free to advance and retire on the guides A A.

D is a prolongation of the piston rod, with a turned joint where the borer F is attached.

On the upper side of the guides A A are teeth or ratches, about 2 in. apart from shoulder to shoulder; these extend to rather more than $\frac{1}{3}$rd of the length from the front end of the guides. About a similar length is occupied by a square-cut screw, on the inside of each guide, which serves for advancing and withdrawing the percussion cylinder C.

The following duties are performed by the machine:—

1. The borer F is projected violently forward, and withdrawn in readiness for another stroke, 250 times per minute.
2. At each fresh stroke the borer rotates on its axis $\frac{1}{16}$th of a revolution to $\frac{1}{20}$th of a revolution.
3. The percussion cylinder C advances as the hole increases in depth.
4. The machine is withdrawn from time to time for the examination, or changing of borers, or on having finished the hole required.
5. The borings are removed from the hole in progress.

1. The compressed air is conveyed to the valve-chest G, of the percussion cylinder C, by a copper pipe. From the valve-chest G there is a passage O, by which a constant pressure is maintained on the annular space of the front end of the piston K; and another passage to the back end of the cylinder, which is covered by the slide-valve L. The rod of this slide-valve is maintained in contact with the disk cam M, by the pressure of the compressed air. The pitch of the cam is equal to the length of stroke required for the slide.

The disk cam is fitted on to the square shaft N, and it is free to advance or retire with C. Motion is communicated to L from the horizontal engine through the bevel wheels p p. The cam M makes a complete revolution for each one made by the engine, and an intermittent motion is consequently given to the slide valve L. On completing the forward stroke, the air at the back end of the cylinder is exhausted in the usual way, and the piston is returned in readiness for another stroke by the constant pressure on the annular surface above referred to, the excess force of the return stroke being absorbed by a cushion of air at P.

2. The rotation of the borer F is effected by a pawl Q, worked by an eccentric fixed on the square bar N, but at the front end of the machine. On the continuation of the piston-rod of the percussion cylinder C is keyed on, at the front end of the machine, a ratchet-wheel R, with 16 teeth, or 20 teeth, through which D slides freely horizontally.

At each revolution of the rotary engine, and consequently of the square rod N, a stroke is given, by the pawl Q, to the ratchet-wheel R, which makes the latter, and with it the borer, turn $\frac{1}{16}$th of a revolution, or $\frac{1}{20}$th of a revolution.

3. Whenever the stroke of the piston in the percussion cylinder is so long as to allow the projecting boss S, on the piston-rod, to strike the catch T, the latter is lifted up, and released for the moment from the ratch, with which it had been in contact; and by an arrangement easily understood by reference to Fig. 3 (Plate 10), it slides over to the next ratch, a distance of about 2 in., being pushed forward by the action of the compressed air on the small piston at its extremity in the valve-chest G.

At the rear of the percussion cylinder, an eccentric, worked from the square bar N, gives movement by a pawl to a ratchet-wheel, the latter being connected with a clutch V, fitting into a screw W, attached to the percussion cylinder. When the piston is working in the percussion cylinder with its average length of stroke, the clutch V revolves without performing work; when, however, the catch is released, the same movement which pushes it forward drags, by connecting rods, the clutch V into gear with the screw W. At every revolution of the square bar N, the ratchet-wheel, the clutch V, and the screw W, turn $\frac{1}{16}$th of a revolution, and the cylinder is gradually advanced, until by its own forward motion it slides, together with the screw W, out of gear with the clutch V, and remains stationary until the operation is again repeated as above described.

4. To withdraw the machine, the pawl is put out of gear, and a small wheel d, on the square bar N, is slid into gear with an intermediate wheel e, which gives movement to f, and with it to the ratchet-wheel, the clutch V, and to the screw W, but in a contrary direction to what has been above described, and the withdrawal of the cylinder, by the rotation of the screw W, is effected.

5. The removal of the borings is effected by a strong jet of water, conveyed through the copper pipe H to the hole in progress.

Workings in advanced gallery.—The different operations of boring, charging, firing, and removing 'déblais' were, in the last

two years, or three years, performed with great celerity, and three complete shifts, or repetitions of each operation, were worked in the 24 hours.

Formerly strong doors were employed, which were fixed from 100 mètres to 150 mètres from the fore-head of the gallery, and removed from time to time as the work advanced. Behind the doors, the frame carrying the set of perforators was removed previously to discharging the holes bored. These doors were suppressed, and the saving of time thus obtained was considerable. The occasional damage done by loose pieces of rock which came in contact with the machinery seems not to have been very great.

Owing to the changes introduced, there is at each end of the tunnel a large stock of perforators, many of them of obsolete form. The Author was informed by the 'employés' in charge at Bardonnèche, that, supposing 20 perforators were required for current work, a stock of 80 perforators was sufficient to insure, at all times, a sufficient supply of them in thorough repair. Thus, for each machine in actual use, there would be 3 machines either in store or in the workshops undergoing repairs.

General observations.—Upwards of 4,000 persons were latterly employed directly on the tunnel. On the French side there were:—

| | | |
|---|---|---|
| 1. In the advanced gallery— | | |
| 'Ajusteurs' | 13 | |
| Miners | 14 | |
| Labourers | 140 | |
| Boys | 13 | |
| | —— | 180 |
| 2. Enlargement by manual labour— | | |
| Miners | 510 | |
| Labourers | 180 | |
| Boys | 30 | |
| | —— | 720 |
| 3. Masonry— | | |
| Masons and dressers of stone | 58 | |
| Labourers | 170 | |
| Boys | 52 | |
| | —— | 280 |
| Carried forward | | 1,180 |

| | | |
|---|---|---|
| Brought forward . . | | 1,180 |
| 4. Manufactories, machinery, stores, and surface works— | | |
| Smiths, joiners, fitters, &c. . . . | 120 | |
| Labourers . . . . . | 440 | |
| Boys . . . . . | 10 | |
| | | 570 |
| 5. Overseers, foremen, clerks, &c. . . . | | 60 |
| 6. Plate-layers, transport of materials, &c. . . | | 180 |
| Total . . . . . | | 1,990 |

| Horse power of machines— | H. P. |
|---|---|
| Hydraulic wheels . . . . . | 480 |
| Ventilating machines . . . . . | 300 |
| Sundry . . . . . | 80 |
| Total horse power of machinery . | 860 |

Horses employed in clearing away débris . . 80

The number employed at Bardonnèche was generally in excess of the above.

Notwithstanding the great cost which is said to have attended the construction of this important work—amounting, if the total sum of £3,000,000 is correct, to £206 per lineal yard—there is reason to suppose that, with the experience now acquired, a similar work could be performed at a cost of £100 per yard, or for less than many shorter tunnels have cost in England, America, and elsewhere.

The time occupied in passing through the tunnel in the train is about 25 minutes.

The Paper is accompanied by a series of diagrams, from which Plates 9 and 10 have been compiled.

Mr. G. J. Morrison said, he had lately seen another machine employed in a tunnel near Bristol, which he had charge of under Mr. Brunlees, M. Inst. C.E. The drill was a hollow cylinder, of about $2\frac{1}{4}$ in. diameter, and its face was set with diamonds. It was fastened on to the end of a tube 5 ft. or 6 ft. long, which was worked at from 180 revolutions to 200 revolutions per minute. The rate of forward progress was about $2\frac{1}{2}$ in. per minute, and in the event of the drill being arrested by any hard substance which would endanger the setting of the diamonds, the advance was reduced by a self-acting friction clutch. The holes made by the drills were from 3 ft. to 3 ft. 6 in. deep, and $2\frac{1}{2}$ in. diameter. There were 8 drills in the machine, and from 22 holes to 28 holes were drilled in the face of the heading, which was about 10 ft. by 8 ft., or as nearly as possible the size of the advance gallery at Mont Cenis.

In connection with tunneling machines, the two points of interest were:—1, the speed; 2, the cost at which the work could be advanced. The rate at which the tunnel was advanced was not so rapid as at Mont Cenis. After the tunnel Mr. Morrison referred to was commenced, it was found that the works with which it was connected would not be ready so soon as was at first expected, and therefore the construction was only advanced at the most economical speed; but even that was four times as great as could have been attained by hand labour. The holes took from 3 hours to 4 hours drilling, the machine was then moved back, and the face of the rock was blasted with dynamite. That operation occupied about 4 hours, so that in 8 hours about 3 ft. were driven, being at the rate of 3 yards per day, or, working 6 days a week, instead of 7 days a week, as at Mont Cenis, at the rate of 18 yards per week. The rock was a hard carboniferous limestone, and no quartz was met with in that part of the tunnel which was excavated by the machine.

As regarded the question of expense, he thought if time was not taken into account, tunneling by machinery was a little dearer than tunneling by hand. In the case to which he referred the expense was not much greater. He thought it worthy of remark, that at the Mont Cenis tunnel there were 180 men employed on the advanced heading, divided into three 'shifts' of 60 men each. With the machine he had described there were about 15 men employed, which at once made a considerable difference in the expense. He had therefore not the least doubt that, under similar conditions, it would be found more economical in use than that employed at Mont Cenis. Although the rate of working was only about 3 yards per day, he was confident that if they had been pressed as regarded time,

Fig. 1.

Fig 2.

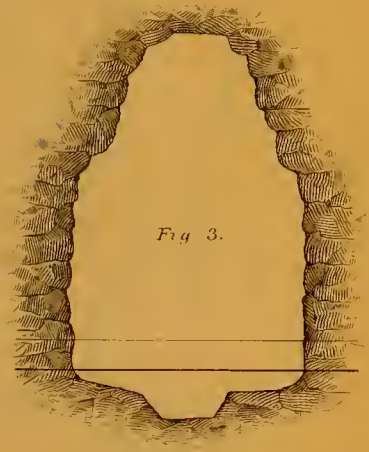


Fig 3.

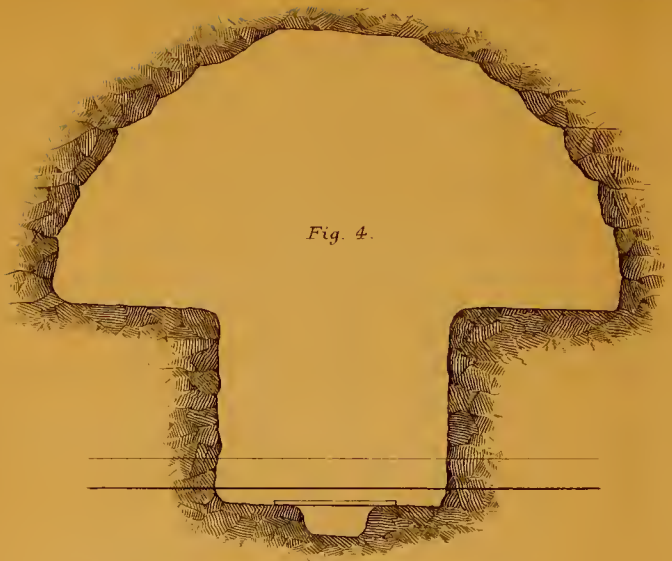


Fig. 4.

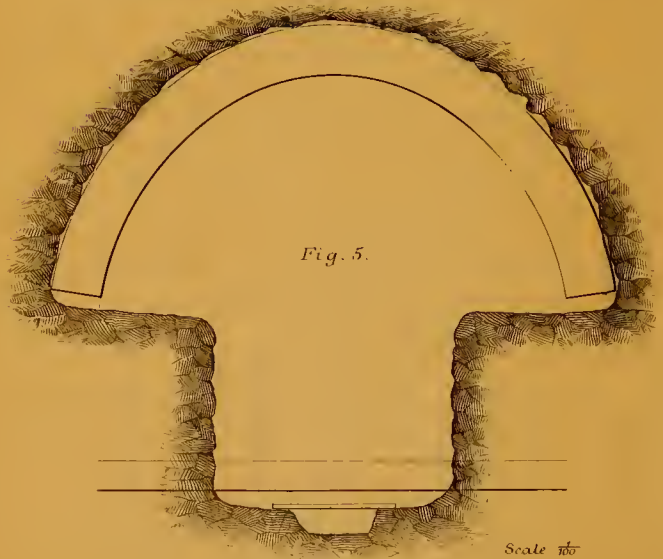


Fig. 5.

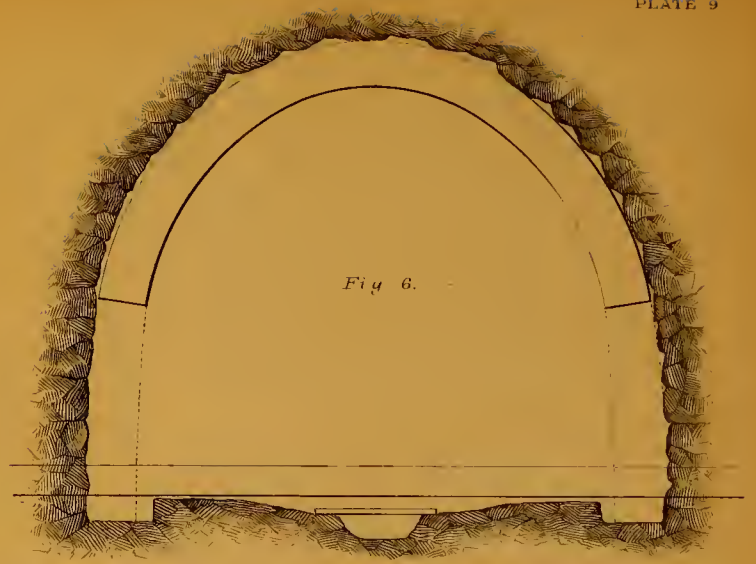


Fig 6.

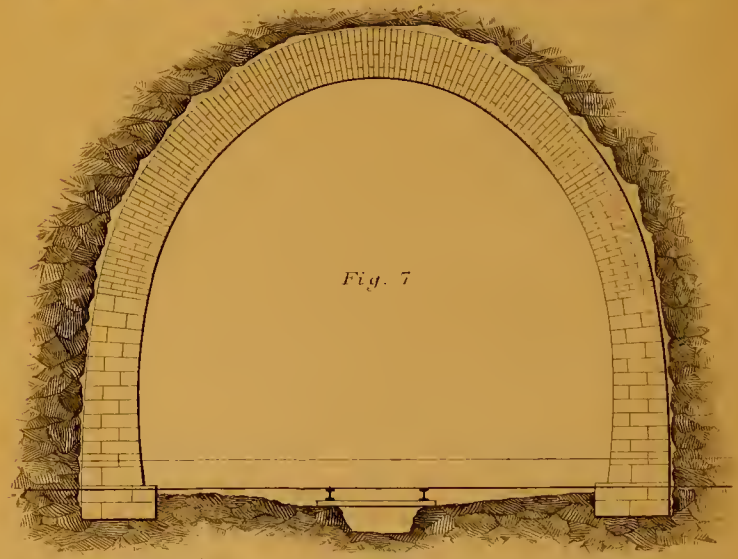


Fig. 7.

Scale $\frac{1}{100}$

Feet 10 9 8 7 6 5 4 3 2 1 0 10 20 30 Feet.

T SOPWITH, JUN$^{R}$ DEL$^{T}$



KELL BRO$^{S}$ LITH$^{RS}$ CASTLE S$^{T}$ H. LEICKN

# MONT CENIS TUNNEL.

PERFORATOR.



*Fig. 1.*

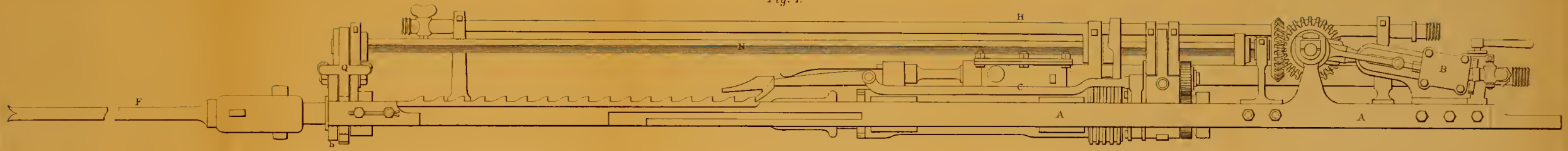



*Fig. 2.*

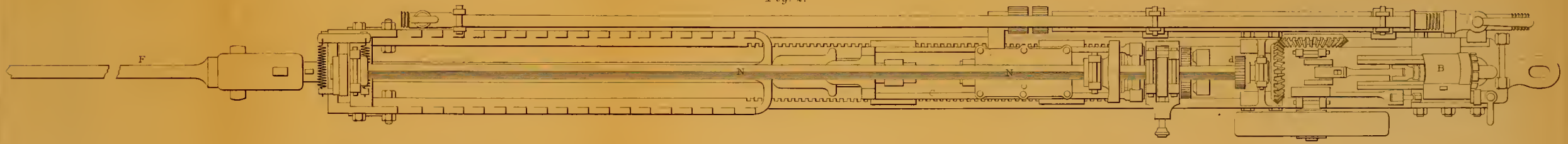
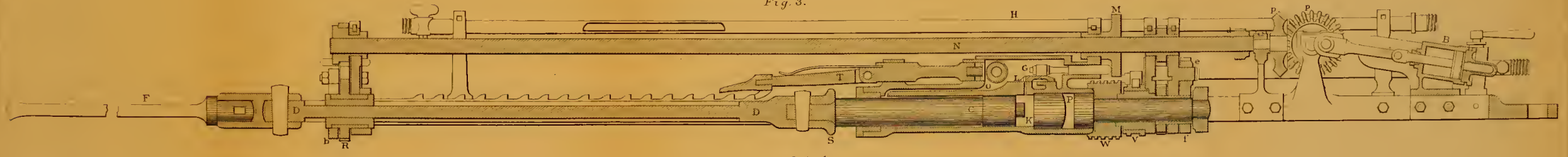



*Fig. 3.*




*Scale $\frac{1}{48}$*

Ins. 12 9 6 3 0 1 2 3 4 5 6 7 8 9 10 Feet

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they could have tunneled 30 yards per week without increasing the expense materially.

With reference to the diamonds, it was at first supposed that it would be a very difficult task to keep them fastened in their places, but some of them had drilled as much as 820 ft. of holes without being worn out. They did not seem to wear, but sometimes they were broken. It was only occasionally there was one lost, and the expense of replacing them was not more than half that of sharpening the steel drills used in working by hand. The diamonds were opaque. He believed they were brought from Brazil; and they cost from £3 to £4 each, according to size. A drill was worth £25 or £30. With hand labour, even when paying the men a premium, and when working day and night, the 'advance' was scarcely more than 3 yards per week.

Major Beaumont, M.P., R.E., said, he was connected with the diamond boring machine, which had just been referred to, and he hoped on a future occasion, when more experience had been gained, to give some additional particulars; but for the present Mr. Morrison's statement had rendered any further allusion to it unnecessary. The criticism which suggested itself in reference to the Paper was twofold:—1, with reference to the method of execution, and the alterations that had been made in the perforating machinery; 2, with reference to the working of the tunnel after its completion.

Referring to the first point, the peculiarity which distinguished Messrs. Sommeiller and Grattoni's machine from other perforators was, that the percussive cylinder and the rotary cylinder were distinct from each other. In most other machines the two motions were combined in one. He gathered from the Paper that this peculiarity remained, while in the general principle there was no notable alteration, the work being done by the motion of a piston in a cylinder, driven by compressed air; the power for the boring remained the same, so that practically the action of the machine was similar to what it was when the Author described it in his previous Paper.

As regarded the next point, namely, the working of the tunnel when completed, there were one or two matters of considerable interest involved. It was stated that the ventilation, notwithstanding the prognostications to the contrary, was satisfactory on the whole; that was to say, it occasioned no inconvenience to the passengers in the trains, although to the engine-drivers and those who looked after the tunnel, it was, to a certain extent, a source of inconvenience. About a year ago, Major Beaumont had

an opportunity of testing it, when passing through the tunnel on an engine, and although the whole height of the Alps was above, he sustained no greater inconvenience than when in the tunnels on the Metropolitan railway, which were only under a street. The engine-driver said that the day was exceptionally favourable for ventilation; but there were times when it was not so satisfactory; and that frequently he had been much distressed in passing through the tunnel. Those variations of atmospheric conditions appeared to be occasioned not only by the difference of level between the two ends of the tunnel, but also by the fact that the north, or French, end was in the form of a cone, up which the north wind drove with considerable velocity, and hence set the column of air in the tunnel in motion. It might be asked why the same thing did not occur at the opposite end? The answer was, in the first place, on account of the difference of level, and secondly, owing to the configuration of the mountain at that point presenting a plain surface instead of a cone. The velocity of the air current in the tunnel depended on the direction and force of the wind outside. To remedy the defects in the ventilation, a project was in course of execution. It consisted of laying an 8-in. pipe along the tunnel, from which, by means of stop-cocks, compressed air could be introduced as required. With the moderate traffic now passing through, Major Beaumont thought that plan might answer, but when the trains ran more frequently, he considered that it would be insufficient. What took place was not the setting of a column of air in motion along an air-way, as was the case in a coal-pit. The vitiated air was not removed, it was only diluted. In the event of the traffic becoming as great as might be justifiably presumed on an international line, there would be a considerable increase of the noxious vapours in the tunnel.

The question of the proper mode of ventilating long tunnels became very important, when it was considered that tunnels of 30 miles in length, such as that under the Channel, were now proposed. He believed the difficulty could be got over by vertically bratticing a tunnel, and letting the trains always run in each section in the same direction that the current of air was traveling. An artificial system of ventilation should also be provided. He was aware that if the wind blew from the north, the artificial stream of air coming from the south would be impeded; but, as he had seen in other tunnels, that difficulty could be surmounted by having large doors at the end of the tunnel, and trusting entirely to artificial ventilation. He considered that the question of the ventilation of the Mont Cenis tunnel, and indeed of all long tunnels, would be found not to present any difficulty in practice which

judicious arrangements might not get over. It appeared to him that a mistake had been made in the laying out of the Mont Cenis tunnel, which had been corrected in the case of another long tunnel, namely, the St. Gothard tunnel. He alluded to the heavy gradient at Mont Cenis from the entrance of the tunnel on the north side up to the summit level. It was true that it was but a little in excess of the ruling gradients of the line leading up to the mouth of the tunnel. It should, however, be remembered that the latter gradients were in the open air; and he believed that the amount of adhesive power of the wheels was less in the greasy atmosphere of a tunnel than outside of it. In the case of the Mont Cenis tunnel it was possible that the adoption of those gradients was unavoidable, but, as a matter of principle, the gradients inside of a tunnel should not be so heavy as those outside.

As regarded the general results which had been attained by the use of tunnel-driving machines, he thought that they had now been proved to be capable of driving tunnels at from four times to six times the rate that they could be driven by manual labour. In reference to the question of price, the information he had received corroborated the statement that the cost of the Mont Cenis tunnel had been over £200 per mètre. The Author had ventured to assume that tunnels in future could be driven at a cost of about £100 per yard. That seemed to Major Beaumont rather a bold prophecy, but, inasmuch as the question of speed was of more immediate importance than that of cost, he would make no further allusion to that branch of the subject; but if the larger estimate was adopted, and tunnels could be driven in one-fifth the time that was formerly expended, he maintained that a manifest advance had been made in practical engineering, from which great benefit would be derived for the public in general; and he would further add that the speed with which tunnels would hereafter be driven would be found to be largely in excess of anything that had hitherto been attained. It was not likely that a great industrial work like the piercing of the Mont Cenis should be carried out successfully—as it had been—without stimulating other enterprises of a similar character, nor that the Alps would remain perforated only in one place. Immediately the connection between the advanced headings of that tunnel had been made, three or four other schemes for perforating the Alps were started, notable amongst which was that of the St. Gothard tunnel. Prince Bismarck, who was never slow to take advantage of what would benefit his country, saw at once that the St. Gothard line was the line best adapted for the requirements of Prussia, and there could be no doubt it was owing to

German influence that that route had been selected. It was a most expensive one to make, because it was not only a question of a tunnel but also of an expensive railway leading up to it—the engineer's estimate for the work being 200,000,000 francs. The Meeting would see that it was not an easy matter to raise such an amount, for, though the line was an international one, it would be some time before a great traffic could be developed. Eight years or ten years might elapse before the attainment of results sufficiently remunerative to tempt capitalists. Consequently, attention had to be turned to aid from the public funds of the countries which would be affected by, and had an interest in, the enterprise. The financial arrangements under which the St. Gothard line was launched were these:—Italy gave 45,000,000 francs, Switzerland gave 20,000,000 francs, and Germany gave 20,000,000 francs; making 85,000,000 francs, which were given as a subsidy to the undertaking. This sum represented rather more than $\frac{1}{3}$rd of the required capital. Under those advantageous circumstances, the 200,000,000 francs necessary for the completion of the work was subscribed in 24 hours.

It might interest the Meeting if Major Beaumont stated the general terms of the contract for the works. Having been himself one of those who tendered for their execution, and the work having fallen into other hands, it would be out of place to enter into details, but at a future time he might be able to make some statements of interest. He would confine himself to what had appeared in the public newspapers. The terms of the contract, as it was let, were these:—In the first place, there was caution money required, to the unprecedentedly large amount of 8,000,000 francs. The next condition was, a fine for every day's delay in the completion of the work, after a given time, of 5,000 francs, or £200, per day. If the delay in completion exceeded 6 months, the penalty was doubled. On the other hand, for every day saved in the completion of the work, the contractor was to receive £200 per day over and above the contract price. It seemed to Major Beaumont that the terms of the contract were exceptionally severe. Before contractors could be found to undertake such responsibilities, it was reasonable to demand that the price should be proportionably increased. It was obvious that such conditions naturally tended to increase the cost to the parties imposing them. Under such circumstances, the St. Gothard contract was not a fair criterion of what such works would cost under less onerous conditions.

A letter which was published in the "Gazette de Genève" gave a comparative statement of the cost of the St. Gothard tunnel. It

was stated that if executed by Messrs. Sommeiller and Grattoni, the Engineers of the Mont Cenis tunnel, it would cost 60,000,000 francs, and if by M. Favre 48,000,000 francs; showing a saving of 12,000,000 francs in money, and one year in time, in favour of the latter. Major Beaumont would not make any remarks upon the contract, but he thought it was quite fair to point out the difficulties which the contractor laboured under in what he had undertaken. The average driving of the Mont Cenis tunnel during the later progress of the work was about $2\frac{1}{2}$ mètres per day. Assuming the St. Gothard tunnel was to be completed in 8 years, and taking the total length of the tunnel at 14,800 mètres, it would be found that M. Favre would have to drive continuously from each end at the rate of 3 mètres per day for 7 years continuously, stopping only 15 days in each year—a rate of progress altogether unprecedented. Major Beaumont would not say the task was impossible of accomplishment, but certainly it was by no means an easy one.

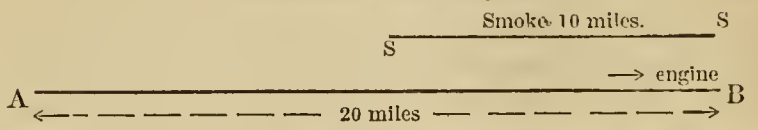
He believed the nature of the strata of the St. Gothard tunnel was rather more difficult than that of the Mont Cenis tunnel. There were about 3 miles, or 4 miles, of granite at the north end, moderately easy to bore and good to blast, but the igneous rock, on the other side, was extremely hard, and though the progress there had been satisfactory, it had, in his opinion, hitherto been so because the superincumbent earth and the strata which laid over the ordinary mountain formation had up to the present time been the only materials reached. In conclusion, he repeated his opinion that the Mont Cenis tunnel would be the precursor and pioneer of many more—possibly even of a larger and more important character than those which were now in course of construction.

Mr. E. A. Cowper said, he believed that it was impossible to ventilate very long tunnels—as, for instance, those of 25 miles in length—so as to allow of a great amount of traffic, unless there was a continuous and brisk current of air blowing through them. If trains passed in both directions alternately, the ventilation was more difficult, and the current of air must be more rapid than if they passed only in one direction, not only on account of the friction of the train, but also on account of the time required to get the foul air out of the tunnel, so as to allow of another train entering.

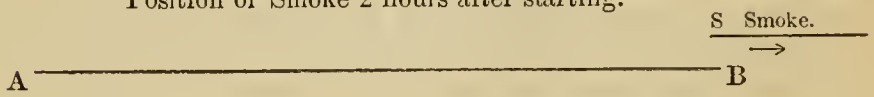
The following diagrams exhibited the case of a tunnel 20 miles long:—

Engine going 20 miles per hour, and Air going 10 miles per hour, in the same direction.

1 hour after starting.



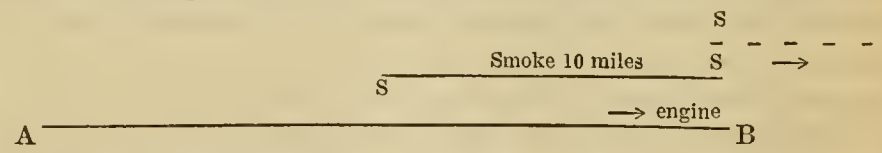

Position of Smoke 2 hours after starting.




Engine going in the opposite direction to the Air. Position of Engine and diluted Smoke 1 hour after starting.

Position of diluted Smoke 2 hours after starting.

Position of Smoke 3 hours after the starting of the Engine that produced it, and position of another Engine 1 hour after its starting in the opposite direction.




The result of his calculations showed that, assuming a train to start from A, running at 20 miles per hour, it would pass through a tunnel 20 miles long to B, in 1 hour, leaving the smoke behind it, as at S S; that, with a current of air of 10 miles per hour, by the time the train was at the end B, the smoke would be half way through the tunnel, and the first half of the tunnel, A to S, would be clear of smoke by the time the engine got out of the tunnel, and in the course of another hour the tunnel would be entirely emptied of smoke. If another train started immediately after the previous one had passed through the tunnel, that train would just overtake the tail-end of the smoke, which was only moving at 10 miles per hour; therefore where there was one tunnel for each line—or a large tunnel with a strong brattice in it—to be kept clear of smoke for passengers, the trains must not be sent at shorter intervals apart than 1 hour. For the traffic between England and France that

would be sufficient. It was obvious that the tunnel might be cleared of smoke more rapidly if the current kept up was quicker; but then the passengers would feel severely the effects of the smoke from the engine.

If a single tunnel only were used, and the trains were sent in opposite directions alternately, 2 hours must be allowed between the ingress and egress of a train. It was obvious that his argument was based on the assumption that there were no shafts, as they would be even more inadmissible in a Channel tunnel than at Mont Cenis.

With regard to the pressure of air required, he found that, if it was attempted to give a current of, say, 25 miles per hour, through a tunnel for a single line of way, 22 miles long, the pressure would have to be as much as $2\frac{1}{4}$ lbs. per square inch to overcome the friction. In the St. Gothard tunnel, and all other very long tunnels, the friction of the air would be very considerable. The longer the tunnel the greater would be the friction of the air through it. The natural motion of the air caused by a little wind, or by a difference of temperature, would not create a pressure at all approaching that required. The draught of a good chimney was only equal to the pressure of about three-quarters of an inch to an inch of water. Therefore it was necessary undoubtedly in long tunnels to close the ends with doors, and pump air in or out to cause a speed of, say, about 10 miles per hour. The good ventilation of a long tunnel would be a serious item in the cost of working, especially when trains were moving in opposite directions, with any considerable amount of traffic. At present he believed there were only two trains per day each way through the Mont Cenis tunnel, and yet that was very foul at times.

Mr. Sopwith. Two passenger trains per day each way, and a certain quantity of luggage.

Mr. Cowper. That was a very small amount of traffic for a tunnel of such importance; and in any tunnel between England and France it would be at least ten times that amount. In all long tunnels mechanical ventilation would be necessary, though he thought there was no occasion to pump air at a pressure of 60 lbs. or 80 lbs. per square inch, as was now proposed for the Mont Cenis tunnel. In that case it was only intended to enable a small pipe to be used to lay on the air to the men in the tunnel at any point that they chose to tap it.

Mr. G. J. Symons said that, the Author, in the portion of the Paper which related to the assumed temperature of the earth's crust, as compared with that found to exist in the tunnel, had

suggested that the temperature of the air at the summit of Mont Cenis should not be taken as the datum temperature, but that obtained at the bottom of a pit, sunk from the summit of the mountain to a depth of about 80 ft. The summit of Mont Fréjus was above the level of the snow line, and higher than Mont St. Bernard, the mean temperature of which was below freezing point. Some eminent Italian philosophers had made observations on other mountains in the vicinity, of about 1500 ft. greater elevation, and from the result of those observations it seemed difficult to understand that the summit could have a temperature higher than 27° Fahrenheit, which was 4° or 5° below freezing point. The question was, what was it that produced a rise of temperature between the surface and the depth of 80 ft. of about 30°? That, if Mr. Symons rightly understood, was the Author's proposition, by which alone he was enabled to obtain a theoretical temperature of 160° Fahrenheit. Now, there existed a certain amount of evidence as to the rate of increase under such circumstances. At Yakoutsk, in Siberia, which was one of the coldest places on the globe, the mean temperature was about 13° Fahrenheit. Experiments had been made there as to the rate of increase of temperature according to depth, and it was found to be solid ice to the depth of 500 ft. A temperature of 32° Fahrenheit was not reached at a less depth than about 600 ft. At 100 ft. it was only 7° warmer than it was at the surface; consequently he failed to see how, with a surface temperature of 27° Fahrenheit, and an increase of 6° or 7° per 100 ft. penetrated, it could amount to 50° Fahrenheit or 60° Fahrenheit at 80 ft. In assuming 27° Fahrenheit as the summit temperature, he quoted from the Report of the Committee appointed by the British Association to investigate underground temperature. He need not say the question became a practical one with respect to the conditions of temperature of coal-mines and of other mines at great depths. If the temperature rose to anything like 160° Fahrenheit, it would necessitate a very large use of compressed air. At the same time, he thought it could not be necessary, as stated in the Report of the Coal Commission, to abandon mining at great depths on account of the increase of the temperature, because if compressed air was used in sufficient quantity the difficulty was got over at once.

Mr. Bewick said, it was stated in the Paper, that out of 80 perforating machines on the Mont Cenis works, only 20 were in use; from which he inferred either that they were defective, or that there was an unnecessary number of machines on the spot. Another point which appeared remarkable, was the great number of surface

men employed, amounting in effect to 25 per cent. He thought if large tunnel works required such a proportion of surface labour and machines as appeared from the Paper to have been necessary at Mont Cenis, it would involve an amount of capital which might prevent many of those works being carried out. He should be glad if the Author would give some particulars of the cost of the respective parts of the work of the tunnel, such as the advanced heading, successive enlargements, &c., either per cubic yard, per lineal mètre, or otherwise. The great extent of comparatively soft rock, namely, of calcareous and carbonaceous schists, had been much in favour of the execution of the work. Mr. Bewick did not think it would be safe to calculate upon the same character of rock occurring in any other tunnel that might be carried through the Alps. It was fortunate for those who had had to execute the Mont Cenis tunnel that they met with such a large proportion of strata comparatively easy of penetration. The thickness of quartz rock passed through was very small. In driving future tunnels through similar rock he had no doubt they might be perforated with much greater speed. He looked upon the work described as the precursor to similar extensive undertakings, and no doubt the experience gained in the prosecution of the work would be of great service in any future operations of the same kind. There was one other point which required explanation. The Author had described Fig. 6 (Plate 9), thus:—"The lower part of the tunnel enlarged to the full size required—a length of a few feet only being extended at a time, with supports, or pillars, left to sustain the arch, which were afterwards taken away."[1] It would therefore appear that pillars were left, from which the arching was erected, and that those pillars were subsequently removed; if that was so, Mr. Bewick did not see how the arching was to be supported.

Mr. W. E. Rich would be glad to hear from the Author whether any special arrangements were made to keep the compressed air, supplied to the air engines, free from moisture? and whether much difficulty was experienced from ice accumulating in the ports and exhaust pipes of the air engines? Those questions were of considerable interest in connection with cold air engines, which were likely to come into more frequent use.

Sir W. G. Armstrong said, he did not think there was sufficient reason for expecting great increase of temperature in a tunnel passing through a mountain. If a depth of 50 ft.—at which the temperature was uniform—was taken as a starting point, it might

[1] *Vide* ante, p. 9.

be taken as certain that in Great Britain, the temperature which was met with, in penetrating downwards in mining, increased at the rate of 1° Fahrenheit for every 60 ft. in depth. At 50 ft. below the surface, there was a temperature which represented the average temperature of the year. In Siberia and the Arctic regions the point of uniform temperature would be very much deeper; but still it would be reached in descending. Starting from that point, at whatever depth it might be, he did not doubt the same increase would go on continuously, namely, that of 1° Fahrenheit for every 60 ft. of depth. It would be more correct to describe this increase of temperature as due not to increasing distance from the surface, but to diminishing distance from the internal sources of heat. The earth must be assumed to consist of a highly-heated and probably fluid mass, jacketed with a crust diminishing in temperature towards the surface. In a flat country the thickness of this crust might be expected to be uniform, and even where the surface varied in moderate undulations of great breadth the configuration of the molten core might be assumed to conform with the surface. But high mountain peaks and ridges should be regarded as excrescences upon the crust, adding to its thickness at the places where they occur. Hence a tunnel passing through an abrupt and lofty ridge might be little or no nearer the internal source of heat than it would be if the superincumbent mountain were removed. The temperature of the external air had no other influence on the question than in determining the average temperature of the year, and the depth at which the constant temperature would be found. At the bottom of a mine the temperature was the same in summer and winter, perfectly uninfluenced by the temperature of the air above. The datum for the temperature of the air at the surface should be the average temperature of the year.

Mr. Cowper asked to what extent gunpowder, and to what extent dynamite was employed in blasting the rock? He believed dynamite would be found to be the more economical material.

Mr. Henry Maudslay would offer a few remarks in reference to the temperature of the air and the working of the machines. The water employed for working the machines was collected from springs at the side of the mountain, and not from the surface snow water. The great length of pipe, and the slight alteration of temperature at the workings, did not affect the working of the engines. Each stroke of the air engines, and the pressure of the air while escaping, made a report like a pistol-shot, and a number being at work at the same time, the noise was very great. He did

not learn, when he visited the tunnel, that there was any difficulty in working the engines, either in consequence of the watery particles in the air freezing, or the character of the air drawn through the engines. The temperature was kept up equally, and the temperature at the workings was sufficiently equalised to enable the engines to work with great regularity.

With reference to the ventilation, he might state that it was a matter of considerable importance, and had always been a subject of discussion even before the tunnel was cut through. In a conversation between himself and the Engineer in charge of the works at Bardonnèche, Mr. Maudslay had suggested that it would not be advisable to take down all the water-wheels, but that an efficient apparatus should be left for the purpose of artificial ventilation, if necessary, until the Engineers had satisfied themselves as to the character of the atmosphere after the working of the trains; because, as the tunnel inclined upwards from each end, foul gases would collect at the highest point, and might affect the character of the air in the tunnel. Whether that had been done or not, he did not know, but in his opinion it was unfortunate for the Mont Cenis tunnel that its entrances were curved instead of direct. The ends were stopped by doors, and the tunnel was not influenced to the extent it would otherwise be by the air passing in either one or the other direction.

Mr. W. W. Evans (of New York), through the Secretary, stated that, diamond-pointed steam drills had, during the last year or so, been extensively used in searching for, and in testing, coal-mines in the United States, Canada, and South America.[1] The machines used for that purpose were styled 'prospecting drills.' In October, 1870, a hole of 2 in. diameter was bored vertically to a depth of about 750 ft., for the purpose of testing the coal veins upon the property of the Phœnix Park Coal Company, near Minersville, Pennsylvania. The average rate of boring was about 18 ft. per day. The different strata penetrated were as follows:—

| | ft. | in. |
|---|---|---|
| Earth, sandstone, and conglomerate rock | 19 | 3 |
| Orchard coal vein | 4 | 1 |
| Slate and rock, with 2 seams of coal | 259 | 10 |
| Primrose coal vein | 11 | 0 |
| Slate and rock | 98 | 5 |
| Holmes coal vein | 5 | 0 |
| Slate and rock with 3 seams of coal | 174 | 6½ |
| Mammoth coal vein:— | | |
| Top bench 7 ft. 8 in. coal | | |
| Slate 2 ft. | 28 | 2 |
| Bottom bed 18 ft. 6 in. coal | | |
| Slate and conglomerate rock | 136 | 6½ |
| Skidmore coal vein | 5 | 1 |
| Slate | 8 | 11 |

[1] *Vide* also "The Diamond Drill." Tract, 8vo. New York.

In January, 1871, a hole of 2 in. diameter was bored 644 ft. horizontally, near Shamokin, Pennsylvania. About 18 ft. of the boring was through slate and coal, and 626 ft. through the hardest conglomerate rock. The average penetration was 20 ft. per day.

The Lackawana Coal and Iron Company were using a number of diamond drills in two large shafts which they were sinking on their coal property near Pottsville, Pennsylvania. One of those shafts was 13 ft. 6 in. by 16 ft., the other was 14 ft. by 21 ft., and they were each intended to be 1,400 ft. in depth. 12 machines had been at work, and 4 rounds, or 5 rounds, of holes had been bored. The following details in respect to the first round had been furnished by General Henry Pleasants, the engineer in charge:—

"Table showing the Number of Feet Drilled each Day.

| Month. | Day. | Number of Machines employed. | Number of Feet drilled daily. | | Month. | Day. | Number of Machines employed. | Number of Feet drilled daily. | |
|---|---|---|---|---|---|---|---|---|---|
| 1872 | | | ft. | in. | 1872. | | | ft. | in. |
| Jan. | 17 | 1 | 14 | 0 | Feb. | 20 | 4 | 127 | 0 |
| „ | 18 | 1 | 36 | 0 | „ | 21 | 5 | 194 | 8 |
| „ | 19 | 2 | 60 | 0 | „ | 22 | 5 | 192 | 3 |
| „ | 20 | 2 | 64 | 10 | „ | 23 | 5 | 233 | 3 |
| „ | 21 | Sunday | | | „ | 24 | 6 | 220 | 7 |
| „ | 22 | 2 | 75 | 0 | „ | 25 | Sunday | | |
| „ | 23 | 2 | 67 | 8 | „ | 26 | 5 | 166 | 8 |
| „ | 24 | 2 | 53 | 0 | „ | 27 | 5 | 231 | 10 |
| „ | 25 | 2 | 80 | 9 | „ | 28 | 3 | 142 | 0 |
| „ | 26 | 2 | 67 | 0 | „ | 29 | 2 | 66 | 1 |
| „ | 27 | 2 | 23 | 2 | March | 1 | 5 | 191 | 10 |
| „ | 28 | Sunday | | | „ | 2 | 5 | 314 | 0 |
| „ | 29 | 1 | 10 | 11 | „ | 3 | Sunday | | |
| „ | 30 | 2 | 10 | 7 | „ | 4 | 5 | 93 | 2 |
| „ | 31 | 3 | 16 | 4 | „ | 5 | 6 | 139 | 11 |
| Feb. | 1 | 3 | 143 | 7½ | „ | 6 | 4 | 145 | 9 |
| „ | 2 | 1 | 33 | 5 | „ | 7 | 4 | 147 | 1 |
| „ | 3 | 2 | 38 | 7 | „ | 8 | 4 | 131 | 5 |
| „ | 4 | Sunday | | | „ | 9 | 6 | 213 | 0 |
| „ | 5 | 2 | 51 | 7 | „ | 10 | Sunday | | |
| „ | 6 | 3 | 46 | 1 | „ | 11 | 5 | 163 | 7 |
| „ | 7 | 3 | 119 | 0 | „ | 12 | 4 | 196 | 1 |
| „ | 8 | 3 | 95 | 3 | „ | 13 | 5 | 219 | 11 |
| „ | 9 | 2 | 69 | 6 | „ | 14 | 5 | 186 | 4 |
| „ | 10 | 1 | 45 | 0 | „ | 15 | 5 | 200 | 7 |
| „ | 11 | Sunday | | | „ | 16 | 6 | 151 | 8½ |
| „ | 12 | 2 | 55 | 10 | „ | 17 | Sunday | | |
| „ | 13 | 2 | 111 | 4 | „ | 18 | 5 | 144 | 1 |
| „ | 14 | 2 | 81 | 10½ | „ | 19 | 4 | 150 | 4 |
| „ | 15 | 3 | 57 | 0 | „ | 20 | 4 | 94 | 1 |
| „ | 16 | 1 | 29 | 9 | „ | 21 | 2 | 114 | 2 |
| „ | 17 | 3 | 57 | 2 | „ | 22 | 2 | 95 | 1 |
| „ | 18 | Sunday | | | „ | 23 | 2 | 45 | 7 |
| „ | 19 | 2 | 31 | 3 | | | | | |

"MEMORANDA.—Total number of holes bored, 25; average depth of each hole, 254 ft.; size of shaft, 14 ft. by 21 ft.; total number of feet drilled, 6,357 ft. 4 in.; total number of working days, 58; average number of feet drilled per day, 109½; total number of machines at work, 12; average number of machines at work, $2\frac{8}{10}$; average cost for wear and tear of bits and diamonds per foot of hole drilled, 13¾ cents; rock bored mostly bluestone and conglomerate; size of hole, drilled with a concave bit, $1\frac{3}{4}$ in. diameter.

"One man attended to two drilling machines.

"The shaft when finished is to be 1,400 ft. in vertical depth. There has been another round of holes drilled upon it, carrying the boring down to a depth of nearly 600 ft., and it has been blasted to almost 500 ft. in depth. Two rounds of holes have also been bored by these machines upon another shaft in the same vein. "'Dualin' and 'giant powder' were the explosives used."

The United States Government had also two of Leschot's machines at work on the James River Improvement, near Richmond, Virginia. Major W. G. Turpin, the United States engineer in immediate charge of the work, in a recent letter, spoke of them as follows:—"No one can be more favorably impressed with the diamond drill than I am. It has met my anticipations fully for drilling under water." In order to show the full value of the drills, it would be necessary to add that the machines had been in constant use since May, 1872.

The Union Gravel Mining Company, of Columbia Hill, California, were using the diamond drill to drive a tunnel 6 ft. by 7 ft. The superintendent wrote:—"We are advancing our tunnel $2\frac{1}{2}$ ft. per 24 hours, and the rock is very hard, but blasts well." The number of feet that one set of diamonds would bore without resetting depended upon the rock operated upon. In slate, marble, and limestone, they were practicably indestructible. Some of the bits now in use had been in constant wear for the past five years in cutting marble, and had never been reset. In sandstone, which was cut as easily as marble, they required frequent resetting, as the sharp grit of the cuttings wore away the steel in which the diamonds were retained. The Hydraulic Cement Company, of Akron, New York, were using a tunnel drill, with a solid head bit, which had been reset but once during a year. In granite, or quartz, the diamonds required frequent resetting,[1] and would in time show signs of wear. With proper care, a diamond bit would bore a given number of feet in any rock, at less cost per foot than the same amount of work could be done with steel drills.

The diamond drills had also been used for submarine work. The

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[1] There are, however, exceptions. One bit has been known to bore 768 ft. through quartz and gneiss, without being reset.—W. W. E.

following were extracts from a letter from Mr. W. G. Turpin (United States Assistant Engineer), in charge of the James River Improvement Works:—

"Since June, 1872, I have had 2 diamond drills in use on James River, in the removal of the ledge known as Rocketts reef. They are $2\frac{1}{2}$ in. diameter; with them we have been enabled to bore circular holes at a distance of 25 ft. from the rock, at right angles to the current, and some at an angle of 60° from the perpendicular."

"The average progress of the bit has been 3 ft. per hour, though run at a low speed, on account of the broken state of the rock. When its character was known, as much as 5 ft. per hour has been bored. Much of the rock consisted of the well-known James River granite."

"The repairs have been trifling, turning up the screw once on the tubing being all that was required. We have lost and broken about $150 worth of diamonds, much of which loss might have been avoided if the work had not been submarine, while some of the loss was the result of carelessness, and want of experience."

"The aggregate penetration somewhat exceeded 1,500 ft."

A diamond drill had also been used in connection with the operations for clearing away the rocks in the Hell Gate Channel, New York Harbour,[1] and the following particulars had been furnished by General John Newton, of the United States Engineers, the officer in charge of the works in respect to its performance between October, 1871, and May, 1872:—

Totals.—Distance bored 4,091 ft.; cost, $1044·82; repairs, $83·78. Cost per foot—for bore, 25·5 cents; of oil, 2 cents; repairs, 2 cents; exclusive of labour, 29·5 cents; including labour, 55·9 cents; air, 32·8 cents.

Mr. Sopwith, in reply, said, the time at which the ventilation was felt to be worst was when the train was going from the Modane end to the middle of the tunnel. In that portion of it there was a steep gradient of 1 in 45. If the train was going at 15 miles or 20 miles per hour, and the current of air had the same velocity, it would be obvious that the train, from the moment it entered the tunnel till it reached the summit, would be entirely enveloped with steam and smoke from the engine. The difference in the rates of the air currents was very remarkable. During a few days he spent in the tunnel on one day the air was almost stagnant, and on the following day he could hardly keep his hat on. He believed

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[1] *Vide* also the "Manufacturer and Builder," vol. iv.—No. 7, July, 1872, New York, for a detailed description of the operations referred to.

the times when the ventilation was bad were very infrequent. With regard to the proposed plan of laying a pipe of 8 in. diameter from end to end of the tunnel, supplied with compressed air at a pressure of 5 atmospheres, or 6 atmospheres, to be discharged as required by stop-cocks—he should say the effect of the compressed air in issuing would not only be that of diluting the vitiated air, as stated by Major Beaumont, but that it would have the further important effect of absorbing a large amount of heat, thus reducing the temperature in the tunnel and hastening the condensation of the watery vapour.

With respect to gradients, it had been suggested during the discussion that an uniform gradient should have been adopted throughout, and that thus so steep an ascent as 1 in 45—as there was now from the Modane end to the summit, or say the middle of the tunnel—would have been avoided. Without entering into details, it might be stated that it was impracticable to make an entrance to the tunnel at a higher elevation on the French side, and inexpedient to select an entrance at a lower elevation on the Italian side; the difference in level between the two entrances was 435 ft., which, equally divided over the whole length of the tunnel—7·6 miles—represented a gradient of 1 in 92. To have adopted that gradient would have required the driving from the Italian end to have been on the 'dip,' or downhill, which under the circumstances, and with a probability of meeting with large quantities of water, was a course no prudent engineer would adopt, or would even entertain. The plan determined upon of driving from the Italian end on a nearly level line was the best. The actual gradient from that end to the summit was only about 1 in 2000, or just sufficient to allow water to run; and the gradient from Modane to the summit was therefore a steep one, for in that distance the original difference in level had to be gained—435 ft.—and in addition the 10 ft. risen in the portion driven from Bardonnèche.

With regard to the alleged cost to the Italian Government—namely, £206 per mètre—the work was sublet to Messrs. Sommeiller and Grattoni at £184 per mètre, and conjectures were made—though they could not be confirmed from official sources—that the actual cost to the contractors was a little over £80 per mètre. When the contract was let, there remained 4,300 mètres to be executed, on which a profit was made by the contractors of about £100 per mètre. Under such circumstances it might be imagined that the employés of the contractors were not willing to afford minute details of cost. In consequence, Mr. Sopwith was unable to obtain such full information as he should otherwise have desired with respect to

the prices of the different sorts or classes of work. The engineers were uniformly attentive and polite to those who visited the tunnel, and gave ably and readily their experience on technical and scientific points, but they were not disposed to enter into details of cost. In defence of his statement that tunnels of this kind might be driven for £100 per mètre, he would urge that not only did he believe this tunnel to have cost the contractors less than £100 per mètre, but that the execution of the St. Gothard tunnel, which was longer, had been let for the whole length at £120 per mètre, and it was expected a large profit would be made out of the contract.

The temperature in the tunnel was a very important matter, although he had only referred to it incidentally in the Paper. It would be remembered that he had stated his views as regarded the probable temperature in the following terms:—"Assuming, for the moment, that the conditions as to temperature at Mont Cenis are not materially altered by its elevation above sea level, and taking a mean of 2° Fahrenheit as the increase of temperature due to each 100 ft., the temperature in the tunnel should be 100° Fahrenheit higher than what would be observed at the bottom of a pit sunk from the summit of the section to a depth of about 80 ft."[1] He might say his reason for believing that at the bottom of a pit sunk at the top of the mountain, the temperature would be 50° Fahrenheit or 60° Fahrenheit, was derived from the theory which had been so lucidly explained by Sir W. Armstrong. Mr. Sopwith might have been wrong in assuming the depth of the supposed pit to be so little as 80 ft., but it was unimportant for his argument whether the depth of the supposed pit were 100 ft. or 200 ft., it was only necessary to suppose it to be so deep as to be beyond atmospheric influences. He had no hesitation in stating his belief that in a pit of the last named depth a temperature of 50° Fahrenheit or 60° Fahrenheit would be found, for just before he stopped at the Mont Cenis tunnel, he had been on professional business in Italy, inspecting mines about 8,000 ft. above the level of the sea. He did not take observations with a thermometer, but the general temperature of those mines was that which was found in ordinary mines, namely, 60° Fahrenheit to 70° Fahrenheit, and that was at an elevation very nearly equal to that of the summit of Mont Cenis tunnel. If it was granted that Sir William Armstrong's supposition of a thickening of the earth's crust where mountain ranges occurred was correct, it might still be open to

[1] *Vide* ante, p. 4.

doubt whether so small an increase in thickness, as compared with the bulk of that part of the interior of the earth—nearly the whole of it—which was supposed to be at an extremely high temperature, would account for so considerable a difference in the ratio of progressive heat as might be inferred to exist under the circumstances, as compared with that which had been observed to exist elsewhere.

It was interesting to observe in the table given in the Paper of the 'rate of progress effected'[1] the improved results which had been attained from year to year since 1863, at which time a great advance had been made on the results formerly obtained by hand labour. He might also add that the machinery was in such good working order that by many it was supposed the maximum of speed which could be attained by machine tunneling had been reached. The number of mètres driven in 1870 was more than double that driven in 1863, and so much confidence had been inspired by the results of machine tunneling that contractors had been found, as stated by Major Beaumont, who had undertaken, under heavy penalties, to execute the St. Gothard tunnel in such a time as would require an annual progress of 2,100 mètres, which was 25 per cent. more than the best results obtained in the best year at Mont Cenis.

By the completion of the Mont Cenis tunnel the following facts, once vigorously discussed, had been satisfactorily proved :—

1. That geodetical operations in mountain ranges, under circumstances of peculiar difficulty, could be performed with sufficient accuracy to insure the setting off, in the same axis and plane, the line of any tunnel which was likely to be required.
2. That an elevation of 5,000 ft. over the line of a tunnel in mountain ranges was not accompanied by an excessive increase of temperature in the tunnel, either whilst in progress or after completion.
3. That the service of removing 'déblais' from the advanced gallery at a distance of 4 miles from the entrance could be effected practically with the same regularity and despatch as at shorter distances.
4. That ventilation during the execution of the works of a tunnel exceeding 7 miles in length could be provided without sinking ventilating shafts.

[1] *Vide* ante, p. 6.

5. That by the aid of machinery a tunnel in hard rock could be driven in less than a quarter of the time which would be required for its execution by hand labour.

With respect to the small number of perforators worked in comparison with the number in the works, in repair or in reserve, Mr. Sopwith could only say, that he had stated the facts as he had found them. In compiling from his notes he had been anxious to avoid any deviation from them, founded on what ought to be, or might be, the result with increased experience. Whether the numerous changes which had been made in the machines from time to time had anything to do with the large proportion kept in stock he would leave to conjecture, but he believed himself that they had. With regard to the surface labour, it had also been a wonder to him that so large a number of men should have been employed as compared with those working inside the tunnel. He believed the returns given him were correct, as they had been taken from the pay sheets of the contractors. The only explanation he could give upon that point was, that it was possible to employ a large number of men in the south of Europe without getting a remarkable quantity of work done. With respect to the section of the tunnel shown in Fig. 6 (Plate 9), alluded to by Mr. Bewick, Mr. Sopwith had omitted to state that pillars of rock, 6 ft. or 8 ft. long, were left in, and that balks of timber were stretched from one pillar to the other. To have shown the pillars would only have confused the drawing. The long length of pipe which conveyed the compressed air was the principal reason why the condensed water —frequently a source of difficulty when compressed air was used— did not reach the perforators in large quantities at Mont Cenis. In the case of the Mont Cenis tunnel, the air was prepared at a low elevation, and used at a higher elevation, whereas the reverse was the case in mines.

April 1, 1873.

T. HAWKSLEY, President,
in the Chair.

The following Candidates were balloted for and duly elected:—CHARLES HENRY BELOE, as a Member; CHARLES BENJAMIN BRAHAM, Stud. Inst. C.E., RICHARD DAVIS, FRANK FITZJAMES, FREDERICK WILLIAM HARTLEY, THOMAS FLETCHER HARVEY, JAMES WOODWARD HILL, ROBERT JOSEPH HUTTON, THOMAS FARMER PARKES, Stud. Inst. C.E., ALBERT WOODWARD PARRY, FREDERICK MANTELL PRATT, JAMES SAMUEL STATTER, and CHARLES EDWIN WARE, as Associates.

It was announced that the Council, acting under the provisions of Sect. III., Cl. VII., of the Bye-Laws, had transferred ELIOTT SCARLETT CURREY and THOMAS WEATHERBURN DODDS from the class of Associates to that of Members.

Also, that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution:—FRANCISCO CORREIA DE MESQUITA CARDOZO, JAMES MILN SMALL, ALEXANDER STARK, BARNABAS JAMES THOMAS, CHARLES HORACE WILSON, and JOHN PALMER WOODCOCK.

The discussion upon the Paper, No. 1,340, "The Mont Cenis Tunnel," by Mr. T. Sopwith, jun., was resumed and concluded.

April 8, 1873.

T. HAWKSLEY, President,
in the Chair.

No. 1,370.—"On the Rise and Progress of Steam Locomotion on Common Roads." By JOHN HEAD, Assoc. Inst. C.E.[1]

THE object of this Paper is to give a history of the rise and progress of steam locomotion on common roads, coupled with a description of the locomotives,[2] or traction engines, made for that purpose up to the present time. The Author does not propose to advocate any special system of construction.

The locomotives referred to may be classified as follows :—

1. Road locomotives for the conveyance of passengers; also locomotives for use on tramways.
2. Road locomotives for the conveyance of goods, heavy weights, &c.; also steam road-rollers.[3]
3. Locomotives for use in agricultural operations, steam ploughing, &c.
4. Road locomotives for military purposes.

About the year 1825, after peace had been established on a firm basis, it was found that Great Britain was in a prosperous condition; and it became apparent that a more rapid communication must be organised between the principal towns than could be performed by horses, except at an enormous outlay, and to the danger of the passengers. The road locomotive was introduced, in an approximately practical form, about the year 1827. Many experiments had been made with steam coaches on turnpike roads by

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[1] The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

[2] The word 'locomotive' is understood to mean a machine propelled by steam, used for the purpose of hauling other vehicles containing passengers or goods, though in some cases the locomotive and carriage are self-contained.

[3] The Author classifies under this division engines used for the purpose of hauling heavy loads, coals, stone, and general goods, at a speed of from 2 miles per hour to 4 miles per hour; and he includes road-rollers, as approaching more nearly to this species than to any other.

Gurney,[1] Ogle, Summer, Maceroni, Hancock, Scott Russell, and others, between the years 1825 and 1834. These carriages were chiefly intended for the conveyance of passengers. Many of them succeeded in traveling at the rate of 20 miles per hour for short distances on good roads; but great hostility was exhibited against them on the part of the British public, partly from a natural distaste for any kind of innovation, and partly because it was found practically impossible to make a law, which should work with equal fairness on common roads for the use of a steam carriage and of a horse coach. Consequently the proprietors of the horse coaches, being in possession, threw such obstacles in the way of the introduction of steam that, after large sums of money had been sunk in endeavouring to make a perfect passenger road locomotive, the problem was abandoned for the time.

During this period, although railways were proposed and in progress, many persons were still in favour of making use of steam on common roads. Some interesting evidence was given on this subject before a committee of the House of Commons in 1831. In "Gordon's Treatise on Road Locomotives" the following paragraph occurs:—"It will be found that with the exception of the Liverpool and Manchester line, and of those lines formed *solely* for the purpose of carrying heavy materials on a descending road, railways are at least of a questionable character when there is the possibility of having a good turnpike road and steam carriages."

The working of the Liverpool and Manchester railway, however, showed that although the first outlay of capital for a railway between two towns was much greater than for a service of steam coaches on the existing roads—on a scale commensurate with the requirements of the time—yet the iron road, laid on a level, must in the end prove successful, on account of the difficulties in the latter system of dealing with increased traffic, the impossibility of manœuvring two carriages, or even one carriage, on a narrow, or badly metalled road, and the common right of every inhabitant of the country to the use of the turnpike road. Railway companies possessed an exclusive privilege, while the proprietors of steam carriages were unable to prevent hostile trustees from fresh metalling the roads, or from imposing tolls, which were often more per diem than the total cost of running the engine. Scientific and commercial men were therefore obliged, for the time, to

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[1] *Vide* "Mr. Goldsworthy Gurney's account of the Invention of the Steam-jet or Blast; and its application to Steamboats and Locomotive Engines." 8vo. London, 1859.

abandon the idea of making use of the existing highways for steam carriages, and left them to be monopolized by conveyances drawn by animals.

Very little was heard about steam on common roads for the next fifteen years. With the exception of two self-propelling agricultural engines, exhibited by Messrs. Ransome — the first at Bristol, in 1846, and the second at Norwich, in 1849—the subject was not revived until about the year 1856. From that time, until within the last two or three years, the attention of engineers, interested in the perfection of locomotives for use on ordinary roads, has been diverted entirely from the question of passenger traffic, and to a great extent from that of the conveyance of heavy goods, and has been principally devoted to the construction of locomotives for agricultural purposes.

Mr. T. Aveling, Assoc. Inst. C.E., Mr. Burrell, Messrs. Fowler and Greig, and Messrs. Clayton and Shuttleworth, have done much to bring the engine used by the farmer to its present state of perfection. The experience of the past twenty years tends to demonstrate that the greatest practical use of the locomotive on common roads, will be for improving and expediting our farming operations, and conveying light loads for short distances. It is to be feared that until the existing laws are altered, passenger traffic by steam power must be abandoned. When the prejudices against it are overcome, it will be found that—by the employment of light engines running on tramways laid on existing roads, with moderate gradients—passengers can be conveyed by steam on the highways with more punctuality and economy, at a maximum speed of 10 miles to 12 miles per hour, than by ordinary omnibuses, or by horse tramways.

## Driving Wheels.

Amongst the component parts of a traction engine, the driving wheels perform the most important functions. They may be classified under the heads of 'elastic,' 'flexible,' and 'rigid.'

An 'elastic' wheel is one which is sufficiently resilient to answer the purpose of bearing springs, but its circumference does not necessarily deviate from a circular form by the pressure of the tread. A 'flexible' wheel is one whose treading face suffers a material change of form as it rolls along, and in addition to the faculty it possesses of acting as a spring, it has a large portion of its periphery continually in contact with the ground. Adams' road wheel (Plate 11, Fig. 5) and Mackinder's road wheel are 'elastic,' but their rigid tires cannot deviate from the circular form. Thomson's india-rubber wheel (Plate 11, Fig. 3), and Bremme's steel

tire wheel (Plate 11, Fig. 6), are 'flexible,' as their tread yields as they roll along. Therefore an 'elastic' wheel merely answers the purpose of bearing springs, and does not practically increase the bite; while a 'flexible' wheel forms a spring, and also increases the adhesion. All other wheels are classed as 'rigid,' because they do not yield to the inequalities of the road.

The adaptation of locomotives to common roads has, for the last fifty years, been a matter of continuous experiments, accompanied by many failures. That it is difficult to design a locomotive, which shall work as well on the highway as thousands of similar engines work on rails, is shown by the fact that during half a century many of the best mechanical engineers have, from time to time, made road locomotives and experimented with them; and yet, at the present moment, with one or two exceptions, they are unable to produce more than an approximately perfect road locomotive either for passenger traffic or for ordinary goods traffic. The 'farmer's engine is the only type which has, as yet, given any really satisfactory results.

The following table, compiled partly from data by Lieutenant Crompton, and partly from other sources, will show the resistance of smooth rigid wheels in lbs. per ton on different surfaces:—

| | |
|---|---|
| On very good pavement. . . . . | 35 lbs. |
| „ good macadam . . . . . | 60 „ |
| „ ordinary macadam . . . . . | 90 „ |
| „ newly-laid gravel . . . . . | 200 „ |
| „ soft grass land . . . . . | 300 „ |
| „ newly-laid metal . . . . . | 440 „ |
| „ a well-laid railway, with moderate gradients . . . . . | 8 lbs. to 10 „ |

From which it appears, that even when the road is in the best order, the rolling resistance is about 8 times that on rails. With the road in an ordinary state, it is from 10 times to 12 times, while, on newly-laid metal, the rolling resistance becomes nearly 50 times that on rails. As almost all roads contain inclines of 1 in 20, or 1 in 30, and as many of them contain inclines of 1 in 10, it will be seen that the actual pull, required to move 1 ton over many portions of macadamised roads, amounts in some cases to more than 100 times that on a railway with moderate gradients. The difficulty of obtaining sufficient adhesion, and the wear and tear caused by rigid wheels without springs, have from time to time led to the trial of various devices for overcoming these defects; but extended experience seems to show, that a rigid wheel, with wrought-iron diagonal bars on the periphery, is the cheapest driver, and, that in many cases, it is sufficiently reliable for the

class of work for which road locomotives are usually required. At the same time, a great demand exists for a reliable 'flexible' wheel for use under certain circumstances where the 'rigid' wheel is almost useless.

The different types of wheels may be appropriated as follows:—

For 'farm engines'—used for thrashing, and for hauling light loads on an estate—'steam ploughing engines,' 'passenger engines,' and for light loads at high speeds, 'rigid' wheels and, in some instances, 'elastic' wheels should be adopted.

For engines designed to ascend very steep gradients, and for engines used for hauling heavy loads on causeways or stone pavements, 'flexible' wheels are required.

The following is a description of some of the principal driving wheels which have been designed:—

Boydell's wheel.—The first wheel which came into extended use in traction engines was termed 'Boydell's endless railway.' It consisted of large flat segments of rails, so jointed round the wheel, that it ran on a species of continuous tramway (Plate 11, Fig. 1). This wheel was patented in 1846, for facilitating the draught of ordinary carriages over soft ground by means of an extended bearing surface, which prevented the wheels sinking. It was partially used for that purpose for several years before it was proposed to adapt it to a locomotive. One of the principal objects the patentee wished to attain, was the transport, by steam, of artillery over roads impassable by horses or oxen. Boydell's wheel, when tried, gave the most satisfactory results as regards the increase of adhesion; and it was shown that it could run with facility over soft land upon which a horse could not move a light cart. The great surface of the shoes in contact with the ground, enabled it to haul great weights over bogs, and to perform many other feats which quickly brought the engine into notice. Indeed its pulling power was so great, that a single driving wheel gave more than sufficient bite for all ordinary hauling work; and, consequently, several engines were constructed with only one side of the machine fitted with the traveling trams—a good plan to save expense, but one calculated to destroy the general efficiency of a locomotive, as its facility of steerage is thereby much impaired.

Boydell's wheel clearly proved that a large surface in contact with the ground tended to an increase of efficiency, but at a great outlay of wear and tear. There was no elastic medium to

deaden the concussion, and the whole apparatus went clattering along, an extraordinary combination of inharmonious mechanism. However, the arrangement was continued for many years; a company was formed to work the patent; about twenty engines were made, and many improvements in detail elaborated, but gradually the whole project came to a natural end. A further account of the actual performances of Boydell's engine will be given under the head of 'Road locomotives for the conveyance of goods.'[1]

Bray's wheel.—Some short time after Mr. Boydell had brought his engines into public use, and when the great advantages of increased adhesion had become clearly known, Mr. Bray, of Kent, brought out his spudded wheel (Plate 11, Fig. 2), by means of which he hoped to gain sufficient adhesion, without complexity and liability to breakage. Bray's wheel had a rigid tire fitted with short strong spikes to dig into the road surface as it rolled along. These spuds could, by an eccentric, be drawn in below the wheel surface, so that it then ran with merely a smooth tire, but when they were projected it was a rigid spiked wheel. The bite of such a wheel on cobble stones—between which the spuds inserted themselves—was equal to cog-gearing, and on macadam the peculiarly shaped spuds inserted themselves into the surface of the road, and produced a similar effect, but to a smaller extent. This plan answered well for some roads, but it was evidently not suited for general use, on account of the damage done to the highways, and the continued breakages in the mechanism of the wheels, caused by the unequal strains on the connecting rods of the spuds.

Wheels with india-rubber tires.—Mr. R. W. Thomson, of Edinburgh, in 1867, constructed a wheel consisting of a very light wrought-iron drum, 4 ft. diameter by 15 in. wide, with flanges 1 in. high on either side. Outside this drum was stretched a flat india-rubber band or tire, 12 in. wide by 5 in. thick. The wheel ran with the india-rubber in contact with the ground. It was found to slip on damp roads and greasy mud. To obviate this, Mr. Thomson covered the india-rubber tire with flat steel plates, or 'shoes.' These were turned over at the ends and joined together by ordinary flat links (Plate 11, Fig. 3), some of which were of different lengths in order to compensate for the elongation of the chain by wear. This species of armour was very troublesome, owing to the continuous breakage of the link pins, and the difficulty of keeping the tire in its place unless the shoes were very tight.

Messrs. Aveling and Greig took out a patent for an improved

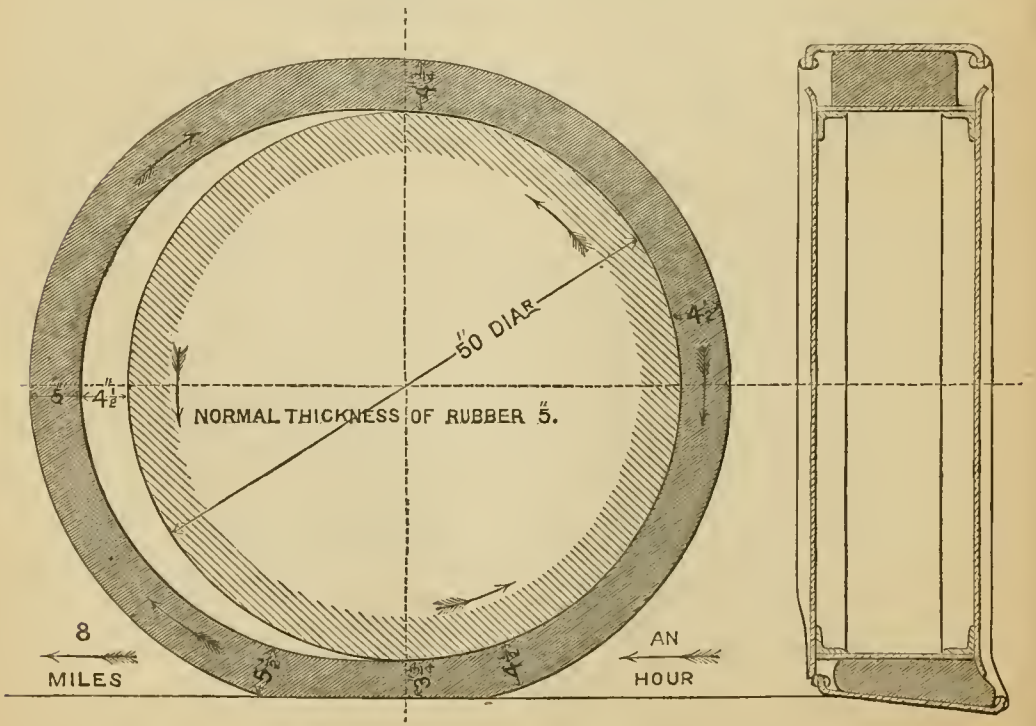
[1] *Vide* post, p. 55.

shoe (Plate 11, Fig. 4), formed of a strong plate turned over at both ends, each side finishing in the form of a hook which was attached to a loop at the end of a wrought plate sliding on the edge of the rim of the driving wheel. The shoes were fixed to the rim of the wheel instead of rotating with the tire. This description of shoe has been attached to several engines manufactured by Messrs. J. Fowler and Co., and has been in work for some time. It remains to be proved how the india-rubber tire will wear, when rotating inside the annular space formed by the fixed shoes and the outer surface of the wheel.

Another system of protecting the india-rubber tire was invented by Mr. Thomson, and improved by Mr. Burrell (Plate 11, Fig. 3). In this case the steel plates touch each other outside the tire, and tapering at the ends, are turned down so as to lap over and clip the angle iron rim of the wheel on both sides, thus permitting the india-rubber to rotate, but preventing it from coming off sideways. The shoe is kept in position, on one side, by a plate fastened with two screws. This arrangement enables any one shoe to be disconnected without taking off all the rest. The system has been found to work well in practice, but experience has not yet shown what will be the wear between the clips at the end of the shoes and the angle iron of the wheel.

The following figures (1 and 2) show the motion of the india-rubber tire when moving without shoes, and also the form which the tire assumes on a convex road :—

Fig. 1. Fig. 2.



Much difficulty was experienced in the early trials of Thomson's wheel, owing to the convexity of the road forcing the india-rubber tire over the angle iron (Fig. 2), thus necessitating guards to keep it in place. The shoes just described will not allow any play in the tire, but nevertheless a great wear and tear is continually taking place through the outward lateral pressure of the india-rubber.

A very curious feature was discovered when working the india-rubber tire without shoes. The tire being loose on the drum, as the wheel revolves, a portion of the india-rubber is continually rolled out to the leading side, where it accumulates until, when running fast, the tire becomes several inches clear of the drum, and as this excess of india-rubber increases, it gradually escapes, by working its way upwards, passing backwards over the top of the wheel. When an india-rubber tire is working without shoes, at a speed of 8 miles per hour, there is a much greater amount of india-rubber on the leading side than on the following side of the wheel. On the leading side the excess of india-rubber accommodates itself by 'bagging out' (Fig. 1), while in the rear it is in a state of tension, and tightly grips the iron wheel. From this action the india-rubber tire is continuously working round with a reverse motion to that of the drum. The rate of this motion depends upon the tightness with which it was originally stretched, its density, its thickness, and the weight on the wheel. If the wheel is very lightly loaded, the tire will scarcely move, while if it is heavily compressed, a great portion of it is rolled out towards the front, and the amount of the reverse action becomes very great. Under ordinary circumstances the tire will move once round the drum in from 30 revolutions to 40 revolutions. It is evident that friction must take place in the india-rubber tire, from its contrary rotation round the iron drum, and also from the continuous change of form it undergoes. No experiments have, however, yet been made to determine the amount.

It appears certain that if india-rubber is used as a tire for the driving wheel of a road locomotive it must be used in the form of a ring, and allowed to rotate. All experiments hitherto made for attaching it in blocks with cement to the periphery of the driving wheel, or of putting it on to the wheel in segments and fastening it by means of slings, have failed.

The india-rubber tire has the great advantage of being a perfect spring to the engine, and it forms a safe and a sure brake. On good macadam its resistance is more than that of the rigid wheel, and on a rough or newly-metalled road, owing to its great surface, it does not sink below the tops of the stones, while the rigid wheel

consumes a great amount of power from sinking into the surface of the road with a crushing and grinding action. Over paved roads the india-rubber wheel, or any other equally elastic wheel, is decidedly superior to the rigid wheel, owing to the increased amount of surface of adhesion; in fact, it has been found that a flexible wheel is almost indispensable for all steam traffic on such roads even with moderate gradients.

One of the principal drawbacks to the use of india-rubber tires is their great prime cost, which appears likely to increase instead of to diminish; also, the impossibility of finding a market for the sale of the worn-out india-rubber. The cost of the tires of the 'Ravee'—the passenger engine built at Ipswich for the Indian Government—amounted to £241. Those of the 'Sutherland,' which were smaller in diameter, but of greater width, cost £234.

With respect to their wear, much difference of opinion exists, but it is impossible to form any correct formula for depreciation, owing to the paucity of the experiments hitherto conducted, and the short time which most engines constructed on this patent have been continually at work.

The Duke of Sutherland, Hon. M. Inst. C.E., states that, after running 1,000 miles during 90 days, the india-rubber tires of his engine, weighing when new 1,337 lbs., were reduced to 1,202 lbs., or about 10 per cent.

Mr. C. F. White, of Aberdeen, who has been working with one of R. W. Thomson's patent 10-H.P. road locomotives for more than two years, writes, that the tires have run 4,400 miles in 309 days, and that their weight was diminished in that time from 1,267 lbs. to 1,133 lbs., or about 10 per cent. He has had them re-lined with thin india-rubber, and expects them to continue for some time in a satisfactory state.

Little experience has been obtained with the performance of india-rubber used for tires in hot countries, and the result of the trials of the Indian engines will be looked forward to by engineers with much interest. Up to the present time, Lieutenant Crompton writes that the tires of the driving wheels wear well, and he hopes to run an engine 8,000 miles with a set.

It is evident that, if the thickness of the tire is materially reduced, the power of the india-rubber to 'float' the engine is diminished, consequently a greater strain is brought upon each cubic inch of rubber than it is calculated to bear, thereby lessening the value of the tire as a spring to the engine.

Much may be said in favour of Thomson's patent tires, but up to the present time, the difficulties of protecting the india-

rubber in a permanently satisfactory manner, coupled with the uncertainty of its action under peculiar circumstances, have to a great extent arrested its employment for the driving wheels of road locomotives. It is, therefore, to be hoped that the attention of mechanical engineers will be directed to overcoming these difficulties.

Adams' road wheel (Plate 11, Fig. 5) is purely 'elastic,' and consists of an ordinary centre and arms, having a heavy T-iron rim, between which and the outer flat tire are inserted treading blocks of india-rubber, about 2 in. thick. These blocks, along with the T-iron rim of the inner part of the wheel, are kept in position by means of two angle irons riveted to the outer ring. A drag link connects the outside tire with the T-iron ring. These wheels, of course, do not increase adhesion, but they act well as moderate bearing springs, and give a great relief to the destructive jolting of an ordinary rigid wheel. They have been exclusively adopted by Messrs. Aveling and Porter up to the present time, but sufficiently extended experience has not yet been had with them to determine how long the india-rubber will last.

Mackinder's wheel consists of an iron drum, surrounded by a series of transverse springs, formed like those used for a railway truck, each fitted with an outer treading-shoe, sliding in guides. A set of these wheels, manufactured by Messrs. Robey, of Lincoln, has run for some months. The arrangement is expensive and heavy, and the sliding shoes would wear rapidly through contact with sand and mud.

Bremme's flexible steel-tire wheel.—In this wheel (Plate 11, Fig. 6), the flexible tire is formed of one or more rings, each of which is constructed of one or more bands of steel, or other similar material.

In practice, the bands are made of steel from $\frac{1}{4}$ in. to $\frac{3}{8}$ in. thick, and from $2\frac{1}{2}$ in. to 4 in. wide. The rings are fixed side by side, and are protected against the road by shoes or tread-pieces. To the tire are attached an adequate number of arms or links, which make the connection between it and the central part of the wheel—that is to say, the arms or links projecting a given distance beyond the periphery of the central part, are able to support the lateral thrust or pressure which the wheel may be exposed to, and are free to adjust themselves radially to any curve the elastic tire may assume under a dead load at the axle.

In driving wheels, the central part receives rotary motion, which by means of the arms is imparted to the tire. When the wheel stands on its tread, the whole load, acting at the centre, is suspended from the upper portion of the tire, while its lower portion is perfectly free to deflect and flatten against the road, thus fulfilling the function of a spring, and producing increased contact surface with the road.

These wheels have been fitted to one of Aveling and Porter's 6-H.P. 'Steam sappers,' at Chatham, and have been found to answer well, but sufficient time has not elapsed to allow of accurate comparisons with other wheels.

Nairn's rope wheel was designed to have all the properties of the india-rubber wheel, at about one-quarter the cost. It consisted of two layers of rope, each 4 in. thick, coiled round a drum wheel, and protected by shoes on the outer surface. It was found in practice that when the rope was coiled loosely enough to flatten at the tread of the wheel, to the same extent as india-rubber, the resistance became very great, through the tire being soft and not elastic; and the rope was soon destroyed. If the coils were wound round as tightly as possible, the tire became almost rigid, and the wheel was not more efficient than one of wrought iron.

These remarks on wheels cannot be brought to a conclusion without citing the careful experiments which were made at the instigation of the Royal Agricultural Society at Wolverhampton, in 1871, by Mr. F. J. Bramwell, M. Inst. C.E., and Mr. J. Easton, M. Inst. C.E. A traction engine of 8 H.P., named 'Sutherland,' was fitted with two descriptions of drivers, namely, one on Thomson's patent, 5 ft. diameter and 15 in. broad, and the other of plain cast iron, 5 ft. diameter and 17 in. broad. A 10-H.P. road locomotive was also experimented upon. It had iron driving wheels with cross-bars cast on the rim, 6 ft. diameter and 18 in. wide. The trial took place on a hill about one-third of a mile long, with gradients varying from 1 in 35 to 1 in 18. After testing the wheels in a variety of ways, the co-efficient of adhesion of the india-rubber tire was found to be, ·45; of the large cross-bar wheel of the 10 H.P. engine, ·35; and of the plain cast-iron wheel, ·244. Taking the gross loads drawn by the engines at different times, it was ascertained that the india-rubber tire would take a gross load of 5 times the insistent weight upon the drivers, up an incline of 1 in 18; the cast-iron tires

with cross-bars, 6 ft. diameter, 3·75 times the weight on the drivers up the same incline; and the cast-iron solid smooth wheels, 5 ft. diameter, not more than 3 times the weight under similar conditions.

Other wheels have been invented for the purpose of increasing adhesion and acting as springs to the engine, but none have proved capable of standing the test of a long journey.

## Passenger Engines.

Space will not permit a description of the various steam engines which have been designed for conveying passengers on common roads. The Author therefore proposes to give a detailed description only of some of those which actually carried passengers, and performed a certain number of journeys satisfactorily. It would, however, scarcely be acting justly to some of the early pioneers of steam road locomotion, if their inventions were passed over without a short notice.

In 1784, Mr. James Watt, whose wonderful genius, it may figuratively be said, broke in and trained the steam engine, took out a patent for a mode of applying it to steam carriages, but no details—so far as the Author is aware—are given of his scheme.

In 1802, Mr. Richard Trevethick invented a high-pressure steam engine and boiler in one machine, of a very compact kind, mounted on 4 wheels. The boiler was cylindrical, and made of cast iron, with the fireplace in the interior of it. The cylinder was vertical and partly inserted into the boiler; the motion being communicated directly to the driving wheels by two connecting rods attached to a cross head. It will not be a matter of surprise that, after experimenting upon the present site of Euston Square, at a period when turnpike roads were very badly made, he discontinued his experiments upon them, and transferred his operations to railways.

About 1812, Mr. Brunton, of Butterly, invented an arrangement of machinery by which a motion was attained similar to that of horses' legs; and in 1824, Mr. Gordon took out a patent, by which an action similar to that of horses' feet could be obtained. It was found, however, that one of the wheels of the carriage, when attached to the steam engine, had a sufficient hold of the ground to give progressing motion without using propellers; and in consequence these inventions were not carried out.[1]

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[1] *Vide* "Gordon's Treatise on Road Locomotives." 1832.

The first passenger engine, so far perfected as to be capable of competing for hire with a stage coach, was constructed by Mr. Gurney, of London; and as early as 1827, his engines were elaborately completed, with almost every required appliance. They were steam coach locomotives, in which the passenger carriage and propelling machinery were combined in one machine (Plate 12, Fig. 1). They were about 22 ft. long by 6 ft. 5 in. wide; below the carriage were a pair of cylinders of 8 in. diameter and 18 in. stroke, coupled directly to a pair of 5-ft. drivers. The boiler consisted of a net-work of $1\frac{1}{4}$-in. tubes, within which was the fire, the necessary draught being caused by a fan blowing into a close ash-pan. In some engines the fan was driven by a small donkey engine, so that its speed could be regulated as required. The engine ran on 5 wheels, and was steered by the fifth wheel. One man in front drove the engine and steered, while another, on a small seat behind, fired, pumped, and regulated the fan. The fuel was coke. There were 12 seats for passengers, and the general appearance of the machine was similar to a large stage coach.

The great defect in Gurney's engine was the cranked axle, which was constantly breaking, notwithstanding it was latterly made of large diameter. The boiler tubes also gave much trouble, from continued leakage, and the passengers complained, that the coach was rough to ride in, had a strong smell of hot oil, and was very close and suffocating.

Several of these conveyances were made and tried. In 1831, one worked four months for hire between Cheltenham and Gloucester, and in that time ran 3,500 miles. Another ran 84 miles in 10 consecutive hours, including all stoppages. Being directly coupled, on good roads they easily attained speeds of 20 miles per hour and 25 miles per hour.

Of the ten or twelve builders of steam carriages between 1827 and 1834, Mr. Hancock, of Stratford, a contemporary of Mr. Gurney, was by far the most successful. Hancock's engines were also self-contained omnibuses, running on 4 wheels (Plate 12, Fig. 2). The cylinders were inverted, 9 in. by 12 in., geared to the main axle by chains, with a ratio of 2 to 1. The drivers were 4 ft. diameter, and either of them could at pleasure be disconnected by clutches. The boiler was about 2 ft. square and 3 ft. high, and was made with flat chambers, 2 in. wide and $\frac{1}{8}$ in. thick, covered with bosses, arranged in such a manner that the bosses of one chamber touched the bosses of the neighbouring chamber, thus forming abutments, and at the same time increasing the heating surface. The outer pressure was taken by 2 strong wrought-iron plates firmly secured

together by cross bolts and girders. The draught was urged by a fan driven from the crank shaft, and discharging into a close ash-pan. The engine was steered by a pinion and chain working a common lock-carriage.

Hancock's carriages were a great improvement on those of Gurney. The main axle was straight, and thus safe from breakage; the engine motion was also well protected from dirt, and the passengers but little exposed to heat. Hancock's carriages were, however, rough to ride in, made much noise, and required considerable attention on the part of the steersman.

After many trials in previous years, Mr. Hancock started a 16-passenger omnibus for hire between the Bank and Paddington in 1833, and a 14-passenger omnibus between the Bank and King's Cross. In 1834, he ran two steam coaches for three months between the City and Paddington, running, excluding stoppages, about 12 miles per hour. In 1836, he had three conveyances for five months on the Paddington road, during which time they ran 4,200 miles, and carried 10,000 passengers. In addition to these regular journeys, many of these engines made single long trips to different parts of the country. One ran from Stratford to Brighton, 57 miles, in 8½ hours, or, deducting 2½ hours for stoppages, in a net running time of 6 hours, making an average speed of rather less than 10 miles per hour, the maximum being as high as 20 miles per hour. Another ran 38 miles in 3 hours 40 seconds, which, deducting 32 minutes for stoppages, makes an average running speed of 12 miles per hour. Again, another ran 75 miles in 12 hours, from which, deducting 4½ hours for stoppages, it appears an average speed of 10 miles per hour was attained. Numerous other isolated trips were more or less successfully made, but cannot here be specially referred to. Mr. Hancock, like Mr. Gurney, met with the strongest opposition from road trustees and others, so that by about the year 1838, he also had abandoned his project of conveying passengers by steam on common roads.

Amongst engineers who devoted their attention to road locomotion at this time was Mr. J. Scott Russell, M. Inst. C.E., then of Edinburgh. His carriages were similar in general appearance to a large family carriage. Two vertical 12-in. cylinders were geared 2 to 1, to a pair of 6-ft. drivers. The boiler was rectangular, with an internal furnace and return tubes on the same level, like a miniature marine boiler. The plates were extremely thin, and the flat form of the boiler was strengthened by a number of small screwed stays. The usual exhaust blast in the funnel was employed. The fore end of the carriage was carried by an ordinary lock fitted

with steering gear. The main frame, carrying the boiler, &c., was hung on springs. The body of the carriage, containing the passengers, was suspended from supplementary 'grasshopper' springs, so that the motion was as easy as that of a private carriage. Behind the steamer was drawn a sort of two-wheeled cart, which carried the fuel and water, and also formed extra passenger seats. This species of tender could be easily changed in a few minutes, if necessary.

These carriages were amongst the most successful ever designed. They ran well and regularly, but at times made a great noise from the blast. Their principal trial was in 1834, when six of them ran for hire between Glasgow and Paisley. They were abandoned chiefly on account of the opposition of the road trustees, who placed every conceivable impediment in their way, at last causing a serious accident, which resulted in the death of several persons.

After Mr. Hancock withdrew his carriages, the conveyance of passengers for hire by steam power on common roads remained in abeyance until Mr. R. W. Thomson again revived the subject during the spring of 1870. In Edinburgh, an omnibus capable of carrying 60 passengers was drawn by one of his ordinary road steamers fitted with india-rubber wheels. The omnibus had two wheels with india-rubber tires, in addition to 5-ft. bearing-springs, so that the motion was rendered extremely easy; indeed, it was so gentle and gliding, that it was impossible to tell when the machinery was put in motion. With a full complement of passengers the rubber wheels became overloaded, and made the resistance so great that it was soon found that loading these wheels increased the resistance in a much greater ratio than was due to the mere increase of weight. This attempt was, for a variety of causes, likewise abandoned.

In the following year, Nairn (of Leith) brought out his self-contained steam omnibus, the 'Pioneer.' In general appearance it was similar to an ordinary three-horse omnibus, with the exception of being a few feet longer. It was 23 ft. long by 6 ft. 6 in. wide, and 9 ft. 6 in. high—measured to the hand-rail. In the extreme rear were 3 cylinders of $7\frac{1}{2}$ in. diameter and $10\frac{3}{4}$ in. stroke, coupled directly to a pair of 40-in. drivers. The boiler had a combination of both water tubes and fire tubes; the grate surface was only 2 square feet, and the water surface was 130 square feet. The funnel passed backwards under the seats of the outside passengers, and emerged behind over the conductor's head. The exhaust was discharged along this horizontal funnel, the opening being regu-

lated by a cone and screw. The single 40-in. leading wheel was carried in a fork, and governed by a hand-wheel and worm. The main axle was fitted with 54-in. flat bearing-springs, supplemented by pendent volutes and india-rubber washers 4 in. thick; the leading wheel was fitted with 4 volutes and india-rubber as before. The weight, with water and coke, was 7 tons 8 cwts., and with 50 passengers, 10½ tons. In the summer of 1871, the 'Pioneer' ran for hire four months between Edinburgh and Portobello, a distance of 3 miles, and from 11 runs to 12 runs were made per diem. It had 20 seats inside and 30 seats outside, or 50 seats in all.[1]

Several passenger engines have been built in Great Britain, within the last two or three years, for use abroad. They have all been constructed on R. W. Thomson's patent, and usually attached to a separate omnibus. Of these, one by Mr. Charles Burrell, of Thetford, was an excellent specimen of careful design and workmanship; but the most worthy of notice were four 14-ton engines manufactured by Messrs. Ransomes, Sims, and Head for the Indian Government. Fig. 3 (Plate 12) gives a drawing of one of these engines, the 'Ravee.' They had cylinders of 8 in. diameter and 10 in. stroke, geared either 3·75 to 1, or 12 to 1, to 72-in. driving wheels. The engines made 150 revolutions per minute, which gave about 10 miles per hour for the fast speed, and 3 miles per hour for the slow speed. The boilers were vertical, on Olrick's 'Field' system, the grate surface was 11 square feet, and the water surface was 177 square feet. The blast-nozzle had an adjustable cone, that the opening might be varied to suit either wood or coal. All the road wheels had Thomson's india-rubber tires, with linked shoes; the leading wheel had supplementary elliptical springs, so that the fore end adapted itself easily to the inequality of the road. The engine drew a 65-passenger two-wheeled omnibus. These locomotives are the most powerful passenger engines which have yet been built, and they have a large tank, and stowage for wood, so that they may run for 15 miles without stopping. They are to carry mails and passengers between two stations in the Punjâb about 70 miles apart. Two of them are already at work.

It was the 'Ravee' which, in October, 1871, made the celebrated double journey between Ipswich and Edinburgh—a total distance of 850 miles—the most remarkable run ever made by any road locomotive. The total weight of engine and carriage was about

[1] Hancock's omnibus only carried about 20 passengers. During 952 runs with the 'Pioneer,' the number of passengers averaged 21, or 42 per cent. of the total capacity.—J. H.

19 tons. By the return journey the men had ample experience in working the engine, and the 425 miles took 9 days, giving 47 miles as the average distance per diem, and a speed of 6·9 miles per hour for the time actually running; but on the last day the average speed was 9·69 miles per hour, whilst, occasionally, a speed of from 15 miles per hour to 20 miles per hour was maintained for short distances.

### Street Tramway Locomotives for Passenger Traffic.

Horse tramways are now laid in various parts of the world, chiefly in towns and their outskirts where roads are moderately level, and where the gradients do not exceed about 1 in 50, or 1 in 40; but sooner or later, steam tramways will form a more general means for transporting passengers and light goods. In order to make an engine which would compete successfully with the present system of haulage by animal power, it should be as light as possible consistently with the amount of traffic. The Author considers that a small engine, weighing from $3\frac{1}{2}$ tons to 4 tons when loaded, would be amply sufficient for drawing a tramway car of the present construction. The outward appearance should be sightly, and, as far as possible, similar in colour to ordinary vehicles running in the streets. The maximum speed should not exceed 10 miles per hour.

Several motive powers have been proposed for propelling street cars, and several of these, such as compressed air, ammonia, and carbonic acid, have been actually tried. Although these and other plans have been made to perform the functions for which they were designed, and might even be useful under exceptional circumstances, it may be taken for granted that the usual means of working street tramways, by mechanical power, will be by ordinary steam engines made and specially adapted for street traffic.

The modes in which steam power has been, heretofore, principally applied on tramways have been:—1, by means of a car containing the goods or passengers, as well as the engine, running upon four, or more wheels; 2, by a detached engine drawing one, or more cars.

The first of these systems has been successfully adopted on some lines in America, but it has the objection that the passengers do not like to be in such close proximity to the boiler; and, if generally adopted, the existing tramway companies would have to purchase entirely new rolling-stock. This principle of construction has, however, the advantage that the whole weight of the car, engine, goods and passengers, can be utilised for adhesion in ascending

heavy inclines. The second system permits the use of all the existing rolling-stock of the present horse tramway companies, with but little alteration, besides being more in accordance with the principle adopted on railways, and generally approved by the traveling public.

With steam as a prime mover, the difficulty is not how to supply the mere tractive force, but how to make the steam power so suited to street traffic that it shall not cause any annoyance. The main objection to an ordinary locomotive working in a street is the 'puffing blast,' and various means have been tried to overcome this defect. First among them may be taken the heavy-geared 'dummy' locomotives of New York. These are fitted with fans, blowing air into the fire-box, driven by a donkey engine and belt. The exhaust from the main engines goes into the tank, from which there is a pipe into the funnel. The donkey engine, however, requires continual attention from the fireman, who has to vary its speed as the locomotive is going up or down inclines, or proceeding at a fast or slow rate. Again, on the elevated railway in New York, a different plan has been proposed to gain the desideratum of a silent engine. The exhaust, as before, goes into the tank, from which there is a pipe into the funnel, but the furnace has a close ash-pan, into which is fitted 'Hancock's blower,' consisting of a square funnel, into the wide end of which are directed nine jets of steam, each $\frac{1}{32}$ in. diameter, regulated by the fireman as the pressure varies.

One of the best street tramway locomotives yet proposed is that designed by Mr. Leonard J. Todd, of Leith (Plate 13). It is, however, only intended for light traffic. The driving motion is placed in a close box on the top of the boiler, so that it may be kept free from dirt and readily accessible. The driving wheels are of the 'Mansell' construction, 6 ft. diameter. The cylinders are doubled, each 5 in. diameter and 9 in. stroke, and the working pressure is 150 lbs. per square inch. The wheels are fitted with steel tires, and motion is given to them by a single pinion and wheel confined in an air-tight case, arranged to give a maximum speed of about 10 miles per hour. One of these locomotives for hauling a single 40-passenger car is calculated to give an effective power of 12 H.P., and it weighs when loaded $3\frac{1}{2}$ tons. An engine of the same construction for two cars, with a maximum of 20 H.P., will weigh 5 tons. A silent blowing fan is placed in direct communication with the close ash-pan, and one end of its spindle carries a bucket wheel on to which the exhaust

from the cylinders is directed through an adjustable nozzle. After thus driving the fan the exhaust enters the tank, where any water is deposited, and the uncondensed steam escapes into the funnel. A small steam pipe from the boiler is also attached to the fan casing, so as to drive the fan when the engine is standing. This apparatus, besides being silent, is self-acting, as it starts and stops with the engine. When going up an incline the back pressure increases and the fan runs fast; when going downhill, the steam being almost shut off from the engines, the speed of the fan is very much reduced, and the blast in the fire-box diminished. The fire-box is furnished with water grate bars to prevent clinkers. A skid brake is attached to the engine as forming a more sure method of slackening the speed than by a brake on to the wheels, and the handle on the engine is connected with the brake to the cars, so that the fireman may have the control of both engine and carriages.[1]

A steam tramway car has been constructed by Mr. John Grantham, M. Inst. C.E. The carriage is about 1 ft. 6 in. longer than the horse cars now in general use. It has two boilers on the 'Field' system; these are placed in the centre, properly 'lagged,' so that the heat does not penetrate into the body of the car. The two cylinders are fixed underneath the frame, and they are attached to the driving wheels in the same manner as in an outside-cylinder locomotive. The front wheels are placed on a sort of turn-table frame, and they can be steered by the driver. The tires of the large wheels are flat, and the car is kept in position by four small guide wheels, which insert themselves in the grooves of the rails. The driver sits on the front platform, where the levers for working the engines are placed, and at the end of the journey they are detached and placed at the other end of the car. The boilers are supplied with coal from a hopper at the top, and the amount is regulated by a valve. The fire can be inspected from a door at the outside of the car.

### Road Locomotives for the Conveyance of Goods.

Much may be said respecting the cost of haulage of goods by steam on common roads, but, as no regular and continuous service has as yet been organized, all data on this subject must be considered approximate. The cost of haulage by steam, as given

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[1] *Vide* also Appendix, III., p. 75.

in the following table, may, however, be considered as approximately correct, though, owing to the continuous fluctuations in the price of labour and materials, it is difficult to form an accurate estimate :—

| | *d.* | | *d.* | |
|---|---|---|---|---|
| Horses on common roads . . . . | 6 | to | 12 | per ton mile. |
| Steam on common roads . . . . . | 3 | „ | 4 | „ |
| Horses on tramway, if nearly level . . | $2\frac{1}{2}$ | „ | 3 | „ |
| Steam on tramway . . . . . | $1\frac{1}{2}$ | „ | 2 | „ |
| Steam on railway . . . . . | $\frac{1}{2}$ | „ | 1 | „ |

Boydell's engine.—Heavy traction engines did not come into general use until about 1856. One of the first was Boydell's engine (Plate 14, Fig. 1). The boiler was constructed on the locomotive type, with the cylinders on the top, and the motion of the engine was transmitted to the driving wheels, which were placed behind, by a pinion working into a large spur wheel fitted to the rim of the drum. The cylinders were double, 7 in. diameter and 12 in. stroke; the driving wheels were 66 in. diameter, and were geared 12 to 1. The construction of the driving wheels has been already described.[1]

A large number of these engines were manufactured by Mr. Charles Burrell, of Thetford, and were found to pass easily over soft ground, and the great surface of the paddles on the wheels enabled them to develop a high co-efficient of adhesion.

One of these engines made a journey from Thetford to London in 8 days, taking a gross load of 29 tons, but in point of speed and cost of haulage the experiment was a failure.[2]

Bray's engine.—Between 1856 and 1866, a few engines were fitted, in different parts of the country, with Bray's spudded wheels. These engines, when running with the spuds, pulled well on most roads, but they jolted so much that they seriously damaged themselves, and, in addition, materially injured the surfaces of the roads over which they ran, besides which, it was found difficult at times to force the spuds out of their sockets when they were required to be put in action. Some of these engines were manufactured by Messrs. Alexander, Chaplin and Co., of Glasgow. One of them, weighing 15 tons, readily took a gross load of 45 tons up a causeway incline of 1 in 30; the adhesion required to attain

[1] *Vide* ante, p. 40.

[2] *Vide* "The economy of steam power on common roads, in relation to agriculturists, railway companies, mine and coal owners, quarry proprietors, contractors, &c., with its history and practice in Great Britain." 8vo. London, page 295.

that result being ·37 of the driving weight, an amount of hold which no smooth rigid wheel would give on a paved street unless assisted by special mechanism.

Taylor's steam elephants.—Mr. Taylor, of Birkenhead, a contemporary of Mr. Bray, brought out a novel design of road locomotive, which he called a 'steam elephant.' The engines constructed upon this design had double cylinders, cog-gear, and very large driving wheels; the boiler was of the marine type, with return tubes. One engine, of 6 H.P. nominal, with cylinders 5 in. diameter and 10 in. stroke, having 6 ft. drivers, and weighing 6 tons, was tested against a number of horses by first ascertaining the greatest load it could draw, and then employing horses to accomplish the same task. It was found to pull as much as 12 strong horses. Subsequently to 1860, several of these engines were constructed, but latterly their manufacture has been abandoned.

Tennant's road locomotive.—In 1869, Mr. Tennant, of Leith, designed a road locomotive. It had outside cylinders, $7\frac{1}{4}$ in. diameter and 10 in. stroke, two gears of $6\frac{1}{2}$ to 1, and 15 to 1 respectively, and rigid drivers 68 in. diameter by 18 in. wide, fitted with cross plates. The boiler was of the locomotive type, with wing water tanks and large bunkers for wood. The single leading wheel was 60 in. diameter, fitted with 5-ft. bearing springs. The main axle rested on 6-in. india-rubber blocks. The weight, in running order, was 14 tons, of which, 10 tons was supported by the drivers.

Thomson's india-rubber wheel engines.—In 1867, it was demonstrated that the india-rubber wheel engines constructed by Mr. R. W. Thomson possessed great tractive power, and therefore that they could be applied to the haulage of heavy loads. On steep inclines of pavement and of macadam, small engines of only 6 tons, or 7 tons, readily drew loads that a powerful rigid wheel engine could hardly have moved. The india-rubber wheels also, from their great bearing surface, enabled the engine to pass easily over soft ground. One was driven for miles along the sea-shore, and actually into the water so far as the fire-box would allow. A 6-ton engine took a load of 10 tons up an incline of 1 in 9, 20 tons up an incline of 1 in 20, and by itself ascended a grass slope of 1 in $4\frac{1}{2}$. A 7-ton engine, with $5\frac{1}{2}$ tons on the drivers, was tested by Mr. Anderson, of Woolwich, by drawing a dead weight over a pulley. On good ground it gave a pull of 63 cwts. with an adhesion coefficient of ·576, and on a less

favourable surface, a pull of 51 cwts. with an adhesion coefficient of ·466.

One of Thomson's engines, with double cylinders 6 in. diameter and 10 in. stroke, with gears of 7 to 1, and 14·6 to 1 respectively, and 60 in. drivers, carrying 5 tons, was, on many different occasions, carefully tested with Tennant's road locomotive. As the latter had twice the weight on the drivers when compared with that on the india-rubber wheels, an excellent opportunity was afforded for proving the coefficient of adhesion between rigid tires and elastic tires. Tennant's engine had 10 tons, and Thomson's engine had 5 tons, on the driving wheels. On a dry and dusty macadam incline of 1 in 12, Tennant's engine took a gross load of 17 tons, giving a coefficient of adhesion of ·32, and Thomson's engine took the same load of 17 tons, with a coefficient of ·499. Again, on a dry macadam incline of 1 in 25, Tennant's engine took 34 tons, with a coefficient of ·3, while Thomson's engine also took 34 tons, with a coefficient of ·5. These two figures, 3 and 5, very nearly represent the comparative value of india-rubber tires and of smooth iron tires on ordinary macadam, as ascertained by the experiments at Wolverhampton. In the trial, each engine took the same load, but Tennant's engine, from its superior boiler power, readily ran twice as fast as its little competitor, the 'pot' boiler of which would only keep steam for the slowest speed.[1]

The 'Sutherland.'—One of the most efficient of the various designs of india-rubber wheel engines has been that of Messrs. Head and Thomson, embodied in the 'Sutherland,' manufactured by Messrs. Ransomes, Sims and Head. This engine had double cylinders, 6 in. diameter and 10 in. stroke; two gears of 9·3 to 1, and 18·4 to 1 respectively, and 60 in. drivers 19¼ in. wide. The 'pot' boiler contained 5·25 square feet of grate surface, and 140 square feet of heating surface. The weight in running order was 10½ tons, of which, 7½ tons was on the drivers. This locomotive was more especially intended for agricultural work, but, when used as an ordinary goods engine, proved to be the most efficient of the smaller class of Thomson's engines, on account of the large heating surface of its boiler, which always furnished an ample amount of steam. At the trials conducted at the Barnhurst farm, at Wolverhampton, in 1871, it was severely tested against several

[1] *Vide* also Appendix, IV., p. 75, for cost of haulage by R. W. Thomson's road steamer.—J. H.

smooth wheel engines fitted with spuds, and, owing to the extraordinary state of the land, which was saturated with moisture and very greasy, the india-rubber wheels proved a failure, but in all engines designed in the future, the outer tires or shoes will be fitted with spuds and spikes, so as to enable them to pass over moist and greasy land. On the hard road, however, the india-rubber wheels proved themselves equal to, and, in some cases, had the advantage over, their competitors; and the 'Sutherland' made the run from Wolverhampton to Stafford, a distance of 16 miles, in 4 hours, or at the rate of 4 miles per hour, with a net load of 12 tons behind it. The consumption of fuel was 3·75 lbs. of coal per ton of load per mile, and of water, 2·05 gallons per ton of load per mile.

The 'Sutherland' was also tested at Wolverhampton, on an incline varying from 1 in 18 to 1 in 35, and about 2,000 ft. in length. It easily took a load of 26 tons up this incline in 10½ minutes, being an average speed of 2·11 miles per hour. The load was then increased to 38 tons, which the engine took up an incline of 1 in 35, and when the load was reduced to 33 tons, it took it up an incline of 1 in 20. In the latter case, the actual pull given by the 'Sutherland' was calculated at 3·38 tons, giving an adhesion coefficient of ·45.

Aveling and Porter's engine.—The present degree of perfection, to which road locomotive machinery has arrived, is in a great measure due to the energy and perseverance of Mr. Aveling, of Rochester. He has, throughout a number of years, by great attention to the working parts, gradually eliminated the weaker portions, until at length his firm has produced thoroughly reliable and durable engines.

A 10-H.P. goods engine, with 10 in. cylinder and 12 in. stroke, and with driving wheels, 6 ft. diameter by 18 in. broad, manufactured by Messrs. Aveling and Porter, of Rochester, made the most successful run, in point of consumption of fuel, in the trials of traction engines between Wolverhampton and Stafford, in 1871. The useful load drawn amounted to 15 tons; the distance run was 16 miles; the time occupied, exclusive of stoppages, was 4 hours 48 minutes; and the amount of coal consumed was 2·85 lbs. per useful ton of load per mile. On that occasion this engine was awarded the first prize of £50.

Some further interesting experiments were made at Orange, United States, in the autumn of 1872, with the object of testing the capabilities of road locomotives, and their commercial value,

in comparison with horse traction. The engine selected for these trials was one of 6 H.P., manufactured by Messrs. Aveling and Porter, of which the following are the principal dimensions :— Cylinder, $7\frac{3}{4}$ in. diameter; stroke, 10 in.; diameter of driving wheels, 5 ft.; breadth of tire, 10 in.; total weight of engine, 5 tons 4 cwts., of which, 4 tons 10 cwts. was upon the drivers; the wheels were of wrought iron, and were fitted on their periphery with strips of iron laid diagonally across the face. These experiments were conducted by Professor Thurston, who gives an interesting account of them in a Paper on 'Traction Engines,' read in January of the present year before the Polytechnic Club of the American Institute. He sums up his remarks with the following comparison between haulage by horses and by steam power :—

"The expense account when doing heavy work on the common road, under the described conditions, by steam power, is less than 25 per cent. of the average cost of horse power, as deduced from the total expense of such power in New York State; while, if we take for comparison the lowest estimate that we can find data for, in our whole country, we still find the cost of steam power to be but 29 per cent. of the expenses of horses.

"We may state the fact in another way: A steam traction engine, capable of doing the work of 25 horses, may be purchased and worked at as little expense as a team of 6 or 8 horses."[1]

One of the most careful and elaborate experiments, ever recorded with traction engines, was carried out in 1866, under the direction of M. Tresca, Sub-Director of the Conservatoire Impérial des Arts et Métiers, Paris, with one of Messrs. Aveling and Porter's 10-H.P. traction engines of the following dimensions :—Cylinder, 11 in. diameter; stroke, 14 in.; diameter of the driving wheels, $6\frac{1}{2}$ ft., with cast-iron rims. The power of the engine was transmitted to the wheel, by means of a pitched chain, in the ratio of 1 to 20 for slow speed, and of 1 to 14 for fast speed. The total weight of the engine, when loaded with coals and water, was $17\frac{1}{2}$ tons, or $14\frac{3}{4}$ tons without coals and water. No pains were spared to elaborate every detail with regard to the performance of the engine under various circumstances; and, after nearly a week's trial, M. Tresca sums up his report as follows :—

"The engine (La Ville de Senlis) drew in a regular manner, upon a good road slightly undulating, a total load of 60,000 kilo-

[1] *Vide* also Appendix, V., p. 76, for a further comparison between the cost of haulage by steam and by horses.—J. H.

grammes (59 tons). The coefficient of traction may be approximately estimated at $\frac{1}{40}$, which would bring the mean strain to nearly 2,000 kilogrammes (39½ cwts.), taking into account the weight of the locomotive. This mean effort, developed at a speed of 1·08 millimètres (3·54 ft.) per second, brings the valuation of effective work to 2·160 kilogrammètres (15,623 foot pounds) per second, or to 28 chevaux vapeur (27·61 H.P.). This figure will appear high if it be compared with the consumption of fuel, which was 184 kilogrammes (3 cwts. 2 qrs. 13 lbs.), in 3 hours and 3 minutes, say 60 kilogrammes (132·25 lbs.) per hour of actual travelling.

"This consumption represents only 2 kilogrammes (4·40 lbs.) of coal per H.P. and per hour.

"The corresponding consumption of water is not less than 600·46 litres (132·22 gallons) per hour of actual traveling. With the present tenders, which can hold 1,800 litres (396 gallons) of water, it is necessary to replenish them every 10 or 12 kilomètres (6¼ or 7½ miles).

"The coefficient of adherence may be estimated on the road gone over at 0·3 of the adherent weight.

"The adherence resulting therefrom was only necessary for the working of the engine up inclines of 0·030 to 0·033 (1 in 33 to 1 in 30), and at starting.

"The load of 81·253 kilogrammes (79$\frac{19}{20}$ tons) which the engine drew on level ground is not the limit of what it can draw under these conditions.

"The speed of 4 kilomètres (2·48 miles) per hour appears suitable for traffic of this nature, and renders the manœuvres so easy that the train is well-managed by a superintendent, an engine-driver, and an assistant solely employed to guide the steering-wheel in front."

Fowler & Co.'s engines.—Messrs. J. Fowler and Co., of Leeds, though they did not compete for the prize at Wolverhampton, have long devoted their attention to road locomotives; and have perfected an excellent engine, which can be used for either heavy goods traffic or agricultural purposes. One of this class (Plate 14, Fig. 3) may be taken as the type of many now in use. The cylinder, 9 in. diameter, 12 in. stroke, is placed on the top of the boiler, which is of the usual locomotive type, with 7·17 square feet of grate surface, and 29 tubes of 2½ in. diameter. The crank shaft is carried on plates riveted to the sides of the fire-box. This forms a compact arrangement. The gearing for transmitting the power

of the engine to the driving wheels, at the rate of 1½ mile per hour, and 3 miles per hour respectively, is of cast steel, and, together with the working parts of the engine, is inclosed, so as to prevent the noise and motion of the engine frightening horses. A compensating gear, enabling the engine to turn sharp corners, which will be hereafter described, is inserted between the main axle and the driving wheels. The driving wheels are 66 in. diameter and 16 in. wide, fitted with india-rubber tires, and Greig and Aveling's patent shoes, but the same engine may be used with wrought-iron tires if desired.

One of Fowler & Co.'s engines fitted with india-rubber tires has been in use for the past twelve months, in hauling coal from Bradford to Messrs. Lister's mill at Manningham, a distance of about 2½ miles, at a cost of 11*d.* per ton of gross load, or 4·4*d.* per ton per mile. The cost of hauling by horses would have amounted to 2*s.* 6*d.* per ton. On the journey from the railway to the mills, there is one gradient, ½ mile long, of 1 in 20; another, ¼ mile long, of 1 in 12; and a third, 1 mile long, of 1 in 40; and the rest of the road is slightly downhill. About half the distance is over a macadamized road, the remainder being paved with cobble stones. It should be stated that this engine, fitted with india-rubber tires, is the first one which has been able to perform a series of journeys, in a satisfactory manner, over the paved roads, which are to be found to a large extent in the north of England. The account of the performances of Fowler and Co.'s engine is worthy of note, as it clearly shows the superiority of the india-rubber, or flexible, tire. On level paved roads there is some adhesion when the stones are quite dry, but in damp weather, an engine with rigid wheels becomes perfectly unmanageable on a slight incline.

A similar engine, but fitted with wrought-iron rigid wheels, was used by the Farnley Company for transporting iron-stone. The accounts show that the iron-stone was carried at 6*d.* per ton per mile. Another engine, the property of the Low Moor Company, transports heavy material on a double journey at 3·2*d.* per ton per mile. This small cost may be accounted for by the fact that, in the two former instances, the engine made only one journey with loaded trucks, returning empty; whilst the Low Moor Company's engine made double journeys in both cases with a load.[1]

[1] *Vide* also Appendix, VI., VII., and VIII., pp. 77–79, for details of experiments made with Fowler and Co.'s engine.—J. H.

## Steam Road Rollers.

These machines have only been brought into use in England during the last few years, although they have been employed in Paris since about the year 1864. The advantages of steam rollers, over horse rollers, are beginning to be appreciated by the highway boards in England. The following extract from Mr. Aveling's pamphlet on road rolling, details some of the advantages to be derived from their use:—

"The economy produced by rolling may be stated in a few words. The road being made for the traffic, and not by the traffic, material is saved; the stones, instead of being left loosely upon the surface to encounter the grinding lateral pressure of the wheels, are forced by direct vertical pressure into the soft bed prepared for them, along with a binding material that fills up the interstices, and affording support for the stones, keeps them in position with one surface only exposed to the abrading action of the wheels. The whole coating is consolidated, and there remains a surface hard and smooth enough to resist the disintegrating action of rain or frost.

"The steam roller, by reason of its weight, will consolidate and prepare for traffic newly-laid macadam at the rate of 2,000 square yards per diem, and by reason of its motive power, can work this greater weight for one quarter the cost of the horse machine. Not only at the same time are the loose stones not torn up, but the heavier roller has the effect of turning down the sharp edges of the stones and leaving their flat sides uppermost, bedding them together in the road, so as to make a solid level surface."

In the road rollers hitherto constructed by Messrs. Aveling and Porter, and well known in many of our principal towns, the engine and boiler represent one of their 6-H.P. or 8-H.P. portable engines placed upon four large rollers, instead of traveling wheels. The two side rollers, situated a little in the rear of the smoke-box, are driven by a pitched chain from the crank shaft of the engine. The centre roller, placed behind the fire-box, is made in two portions, turning, for facility of steering, separately upon their axle, and carried in a turn-table frame, constructed with only two carrying wheels, allowing it to swivel vertically to a slight extent, for the purpose of giving the rollers sufficient play to accommodate themselves to the convex surface of the road.

The sizes most in use are those weighing about 15 tons and 20 tons, with driving wheels respectively 5 ft. and 5½ ft. diameter.

The working expenses for rolling 2,000 square yards per diem

may be calculated at about 15*s.*; but much depends upon the state of the material to be operated upon. An average of from 10 square yards to 12 square yards may be rolled and consolidated for 1*d.*

After several years' experience with the road rollers described, Mr. Aveling discovered that they were rather too heavy for making new roads, and too broad for narrow, and crooked, places, in addition to which, they were not well adapted for haulage, an important feature in the economy of road construction by steam power. He therefore designed a new road roller (Plate 15, Fig. 2), which somewhat resembles one of his traction engines, with the driving wheels converted into rollers, and the space between them covered by a pair of front rollers, which also act as steering wheels. These front rollers are made conical, or dished, in order that on the ground line they may be close together; while above their axle there is a space for a vertical shaft, serving as a support for the front of the boiler. To the extremities of this axle a forked, or saddle piece, is attached, to act as a guide for the steering chains; and these chains pass rearwards to a transverse roller, which is acted upon by a worm and pinion connected with the steersman's wheel. By keeping the driving wheels behind, instead of in front, as in the engines previously described, the greatest bite is obtained in ascending inclines and going over soft places. Besides being capable of hauling trucks, this engine is furnished with a fly-wheel, and can be used for driving a Blake's stone-breaker, or any other machinery connected with road-making. Its weight is about 8 tons, and the nominal power of the engine is 5 H.P.

In Paris the 'Gellerat' system of steam road roller has been employed (Plate 15, Fig. 1). This engine has been manufactured in this country by Messrs. Manning, Wardle and Co., of Leeds. It has two cylinders, each 7 in. diameter, and 11 in. stroke, mounted on a locomotive boiler with 285 square feet of heating surface. The rollers are 3 ft. 11 in. diameter, and 4 ft. 7 in. wide, and are connected to the engine by means of pitched chains. The large-sized engines weigh 30 tons, and the small-sized engines weigh 15 tons. On the side of the engine where the attachment is made with the crank shaft, the axles turn in radial boxes, fixed to horn plates, similar to an ordinary locomotive; whilst on the other side, the axle-boxes are free to move backwards and forwards, sliding on the frame of the engine, and connected together by a rod with a male and female screw worked from the foot-plate by a vertical shaft connected by bevel wheels with the steersman's handle. When the engine moves in a straight line the axles are kept

parallel; but when necessary to turn a corner, the centres on one side are drawn together, and, consequently, the rollers act like a double steering wheel, turning the engine in a very small space.

From the reports of the road surveyors in Paris, it appears that the cost of steam road rolling is estimated at 7*d.* per ton per mile; whilst horse rolling was usually contracted for at the rate of 14*d.* per ton per mile.

Another road roller has been invented and manufactured by Messrs. Morland and Sons, of London. It consists of a large rectangular frame about 20 ft. long by 8 ft. wide. The two cylinders are 11 in. diameter by 18 in. stroke, and are placed at one end of the frame, with a single chain gear of 5 to 1 to the driving-roller, which is 7 ft. 6 in. diameter, and 6 ft. wide. The machine is steered by two wheels, at the opposite end of the engine to the cylinders, each 3 ft. 6 in. diameter and 12 in. wide. The boiler is vertical, on the 'Field' principle, 4 ft. 2 in. diameter, and 10 ft. 3 in. high, with 64 tubes, $2\frac{1}{4}$ in. diameter. The total weight of the machine is $25\frac{1}{2}$ tons.

## Locomotives for use in Agricultural Operations, Steam Ploughing, &c.

The application of steam to agriculture is a subject too important and extensive to be properly treated in a section of a Paper. One thing is, however, certain—that, in spite of all the obstacles which have been created by Acts of Parliament, local courts, and private individuals against the introduction of agricultural road locomotives into Great Britain, their number has greatly increased; and every year, as the price of horses augments, farmers discard the mode of working in which they were educated, and have recourse to steam to assist them in their difficulties.

The increasing use of steam-ploughing machinery, and the perfection to which the present apparatus has been brought by Messrs. Fowler and Co., coupled with the extensive employment of tackle on English farms—even where it is necessary to fill up ditches, cut down time-honoured fences, and level a large tract of land, in order to operate upon it quickly, thoroughly, and economically—all tend to show that the use of steam in agriculture is daily increasing.

Although several excellent farm locomotives are in use—amongst which we may cite those of Messrs. Aveling and Porter, Mr. Charles Burrell, Messrs. Fowler and Co., and Messrs. Clayton and Shuttleworth—there is not much novelty in the construction

of these engines, and they really consist of a portable engine fitted with various methods of transmitting the power from the crank shaft to the road wheels.

The chief difficulty, which has beset engineers in the construction of this class of machinery, has been the impossibility of theoretically calculating the varied strains to which the component parts of such an engine are subjected, in the same manner as in a railway locomotive. The principal proportions of the engines referred to in this Paper have been the result of long and careful experience and laborious experiment.

The first self-moving engine, used for driving a thrashing-machine, was exhibited at Bristol by Messrs. Ransome in 1846, and the following account is given of its performance in the journal of the Royal Agricultural Society of England:—"Messrs. Ransome's collection contained the excellent portable disc-engine (tried at Liverpool), now set upon a carriage with four instead of two wheels, and having a platform of sufficient dimensions for the conveyance of a thrashing-machine from farm to farm. A further change had been made, by applying the power of the engine to give locomotion to the carriage instead of using horses." The judges "consider it questionable whether the substitution of steam for horses, as the force employed to move agricultural steam-engines from place to place, will be found either more convenient or economical; they cannot, however, but highly commend the simplicity and effectiveness of the machinery applied by Messrs. Ransome to accomplish this purpose. The engine travelled along the road at the rate of from 4 to 6 miles an hour, and was guided and manœuvred so as to fix it at any particular spot with much ease."[1]

The next self-moving engine, specially adapted for agricultural purposes, was also constructed by Messrs. Ransome, and was exhibited by them at Norwich, in 1849 (Plate 16, Fig. 1). It consisted of a miniature locomotive, with two cylinders, $6\frac{1}{2}$ in. diameter, 10 in. stroke, placed under the smoke-box of an ordinary locomotive boiler. The power was transmitted to the road wheels by means of spur wheels and pinions, geared so as to produce two speeds, namely, one for thrashing, and one for traveling at the rate of $3\frac{1}{2}$ miles per hour. The engine could be steered from the foot-plate, or by means of a horse attached to shafts fixed to the fore carriage of the engine. When it was required

[1] *Vide* "The Journal of the Royal Agricultural Society of England," vol. iii., page 351.

for driving a thrashing-machine the fire-box was blocked up, and a strap taken from one of the driving wheels to the drum-pulley of the machine; but this arrangement was not found to work well in practice, and this type of engine was abandoned for those with the cylinder placed on the top of the boiler working a fly-wheel independent of the road wheels. The following extract from the journal of the Royal Agricultural Society, will show that farmers were in 1849, as in 1846, decidedly prejudiced against road locomotives:—

"This engine, excellent in workmanship, was fitted with two cylinders; its weight for the power very light, and strong in all the working parts; the boiler tubular, and beautifully made; but we think such an engine not suitable to be put into the hands of farmers' engine-men generally, and should doubt its locomotive powers being of much practical benefit as connected with agriculture, entertaining a fear also that accidents might be of frequent occurrence in steaming from farm to farm." [1]

About 1856, Boydell's engine was manufactured by Charles Burrell, of Thetford. It was thought that it could be satisfactorily used for farming operations. Many experiments took place to show its capabilities for traversing bad roads, farm-yards, &c., and also for ploughing by direct traction, but this system became disused, partly on account of the cost of the engine, and partly from the great wear and tear of the wheels.

In the same year, Mr. Charles Burrell brought out a self-moving agricultural engine, in which the power was transmitted to the driving wheel by a pitched chain, and he has successfully carried on their manufacture up to the present time, a large number of his engines being at work in the eastern counties and other parts of England. Fig. 2 (Plate 16) represents Burrell's improved farm locomotive. The boiler is multitubular, of the usual locomotive type; the cylinder is 9 in. diameter, and 12 in. stroke, and the motion of the crank shaft is transmitted to the driving wheels—5 ft. 6 in. diameter—by means of two pitched chains, one on each side of the engine; thus relieving the main axle of the undue torsion which is liable to occur when only one wheel is coupled. Each chain pinion is provided with a clutch, so that the driver may disconnect either wheel when turning corners. The hinder part of the engine is mounted upon volute springs, set at an angle, so as not to

[1] *Vide* "The Journal of the Royal Agricultural Society of England," vol. x., page 552.

interfere with the movement of the chains, and it has been found in practice that the use of springs diminishes, to a great extent, the wear and tear of these engines. The driving wheels are made with wrought-iron spokes and cast-iron naves and rims, the latter partially covered with wrought-iron diagonal plates.

Mr. Aveling, well known as an agricultural locomotive manufacturer, exhibited his traction engine for the first time at the Royal Agricultural Society's meeting at Canterbury in 1860, but it was not until the year 1871, that the Society considered this class of machinery sufficiently useful in agricultural operations to be placed on the competitive list of prizes.

In the first engines designed by Mr. Aveling, the transmission between the crank shaft and road wheels was effected by means of a pitched chain, and the engine was steered by a fifth wheel in the form of a disk, placed at the end of a wrought frame fixed to the fore axle.

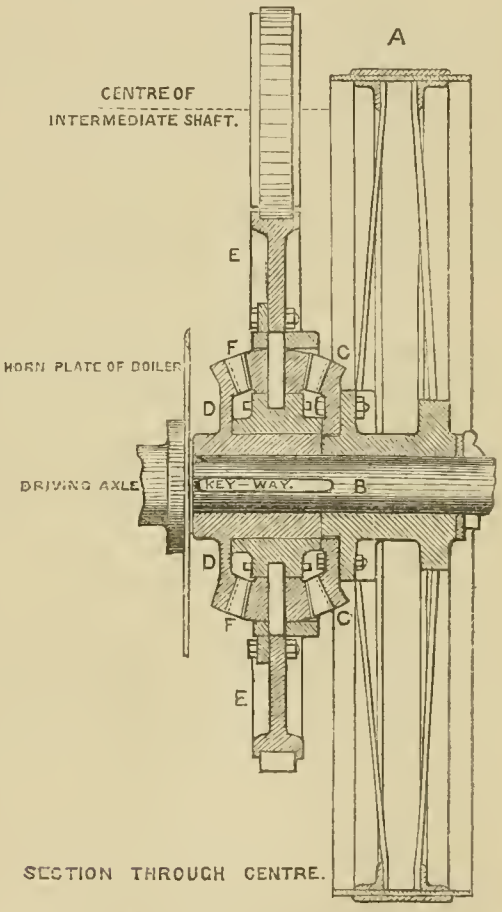
Fig. 3 (Plate 16) represents one of Aveling and Porter's most recent 8-H.P. agricultural locomotives. The general design outwardly resembles some of the engines already described, but care has been taken in the manufacture to make every part as light as possible, consistently with the work it has to perform. The boiler is of the usual locomotive type, with 4·3 square feet of fire-grate surface; 30 tubes, $2\frac{1}{2}$ in. diameter; total heating surface, 130 square feet. The cylinder is 9 in. diameter, and 12 in. stroke, and is placed at the forward part of the boiler surrounded by a dome, from whence the steam is taken to the slide valve. The motion is transmitted by gearing, the toothed wheels being made of malleable iron to prevent breakage. An arrangement is provided for disconnecting the crank shaft from the train of wheels, so that the power of the engine may be used for driving a thrashing-machine, corn-mill circular saw, or any other machinery used on a farm, through the medium of a fly-wheel placed on the side of the crank shaft opposite to the wheels. The main plummer blocks are supported on the outside plates of the fire-box, which are carried up to the requisite height. This arrangement combines lightness with strength, avoiding many of the breakages which used to occur with the cast-iron saddles formerly used.[1] The driving wheels are 66 in. diameter, 12 in. wide, and may either be constructed

[1] This is 'Aveling's patent.' It avoids the necessity of heavy saddles bolted to the boiler.—J. H.

of cast iron, wrought iron with diagonal strips, or with india-rubber springs on Adams' patent.

These engines, as well as those of Messrs. Fowler, are provided with a compensating or differential gear (Fig. 3) for transmitting the motion of the crank shaft to the driving wheels, thereby enabling the engine to turn sharp corners without the use of disengaging-clutches :—

Fig. 3.




Compensating or Differential Gear for the Driving Wheels of Traction Engines.

One wheel A turns freely on the shaft B, whilst the other on the opposite side is keyed fast on to the axle. The bevel wheel C is bolted to the nave of the wheel, and one of equal size D is keyed fast to the shaft. Between these the spur gear E revolves, driven by the pinion on the crank shaft, and it carries in two recesses a couple of small bevel pinions F F, both gearing into each of the larger bevel wheels C and D.

An examination of this combination will show that, resistances being equal on both wheels, if the spur gear E is turned, it will carry with it both driving wheels at the same time with equal

angular velocities, the effort exerted by the engine being equal on both wheels at all times; but in turning a corner, the greater resistance on the inside wheel retards it, while the outer wheel necessarily moves more rapidly over its longer path, and, as the engine exerts the same force on both wheels, the work done is distributed unequally between them through the revolving bevel pinions, without either wheel being necessarily slipped or disengaged.

Steam ploughing engines.—Fowler and Co.'s steam ploughing engines being constructed so as to move themselves on the road, and haul not only the implements which form a part of the tackle, but also wagons from one part of the farm to another, come within the range of locomotives on common roads. The description of these engines is intimately associated with the interesting history of the steam plough invented by the late Mr. John Fowler, assisted by Mr. David Greig. Their united persevering energy and thorough knowledge of the subject have completely overcome difficulties of construction and hereditary opposition to the adoption of an entirely new system of culture. The machinery which will be hereafter described may be considered as the latest combination of their practical experience and scientific research.

The 'double engine' system of steam ploughing—in which each engine is placed on the opposite headland of a field, and in which they move themselves at intervals and alternately wind up, or pay out, the steel rope which hauls the implements to and fro—having been found the most economical and practical in the variety of trials to which steam ploughs have been subjected for several years, the Author has selected the 12-H.P. engine of Messrs. J. Fowler and Co., of Leeds, as the most perfect specimen of a steam ploughing engine yet designed (Plate 17). The boiler is of the ordinary locomotive type, the area of fire grate 7·6 square feet, and the total heating surface 201·24 square feet; the average pressure in the boiler is 150 lbs. per square inch; the cylinder—10½ in. diameter, and 12 in. stroke—is steam-jacketed, and is placed in the smoke-box end of the boiler where the steam is dryest; the crank shaft is placed at the far end of the boiler, and the fly-wheel is within reach of the driver; so that in case the engine stops on the centre—which rarely happens—he can make use of it for getting the crank over the dead centres; the main plummer blocks are carried on plates forming an elongation of the side of the fire-box. The road gearing, which gives a fast speed of 3 miles per hour, and a slow speed of 1½ mile per hour, is made of cast steel; and throughout, the engine is manu-

factured of the best material, and in the strongest form, so as to avoid breakages even under the most extraordinary circumstances. The driving wheels are 66 in. diameter and 20 in. wide, made of wrought iron and faced with diagonal plates; and the rope drum, with the automatic coiling gear, is fixed by a strong wrought-iron stud to the bottom of the boiler. The capacity of the coal bunker is 8 cwts., and of the water tank, 180 gallons. These double sets of steam ploughing tackle are manufactured of 10 H.P., 12 H.P., 20 H.P., and 30 H.P.

At the trial of steam ploughs at Wolverhampton in 1871, the 20-H.P. engine, for working a double set of steam ploughing tackle, manufactured by Messrs. J. Fowler and Co., with a cylinder of 13 in. diameter, and 14 in. stroke, indicated as much as 143 H.P., and one of the same class of engines, 12 H.P. nominal, with a cylinder of $10\frac{1}{2}$ in. diameter, and 12 in. stroke, indicated 103 H.P., and another, 68 H.P.

It may also be interesting to state that the following data, respecting the cost of power in steam ploughing, was deduced by the judges at Wolverhampton in 1871 from the various experiments and trials which were carried out at that time :—

The average consumption of coal = 161 lbs. per acre.
" " water = 115 gallons per acre.
" " oil and tallow = 5·1 ozs. per acre.
" " water per lb. of coal = 7·2 lbs.
" " coal per mean I.H.P. per hour = 7·1 lbs.
" weight of earth moved per lb. of coal = 9·3 tons.

## Road Locomotives for Military Purposes.

So little experience has been gained in the employment of road locomotives for hauling heavy guns, siege trains, and transport wagons in time of actual war, that no reliable data exist for forming a practical opinion upon this subject. It has, however, for some time, been the opinion of some of our most experienced engineer and artillery officers, that steam power may be advantageously employed as an important auxiliary to an army on the march.

An engine can develop, at least, the power of 10 horses. It costs nothing when not in use. It can work night and day without fatigue or requiring rest, consequently its power is always at hand, and can be used at any moment and to the fullest extent.

A road locomotive can be used as a fixed engine, to saw wood, or

pump water. It can be employed for transporting guns, or other war material, and is specially useful in the neighbourhood of a fortress, as the traction engine with its train would form a much more rapid means of communication with detached railway stations than ordinary carts or wagons drawn by horses or bullocks. The Prussians at Metz constructed a line 20 kilomètres long in order to skirt the fortress of the city, but it was not required as the garrison capitulated before its completion.

In addition to the above uses, the engine can be so constructed that flanged railway wheels may be substituted for the ordinary rigid wheels used on common roads, and it will then serve as a light railway locomotive in case the enemy may have destroyed or secured the rolling-stock on the existing railways.

A traction engine for military purposes should be made as light as possible, and constructed almost entirely of wrought iron or steel, in order to diminish the chances of breakage. Its weight should not exceed 5 tons, with about 72 cwts. on the driving wheels, so that it may be able to pass over pontoons as at present constructed, and also over temporary wooden bridges hastily made to repair the arches in masonry or iron blown up by the enemy. It should be furnished with a powerful windlass arranged in such a manner that the engine after having ascended a hill, or traversed a soft road or marsh, could remain stationary and haul the guns or wagons up the incline, or through the bog by a steel rope. Heavy loads could thus be dragged through difficult places almost inaccessible for horses.

Messrs. Aveling and Porter have constructed several traction engines for the Royal Engineer Department, weighing not more than about 5 tons, and they have been used with great success for various military purposes. They have safely transported 5-ton guns over pontoons of ordinary construction. They are furnished with a train containing all the machinery for sawing and preparing wood for siege purposes, are adapted for pumping, and, lastly, can be used as fixed engines for winding, or as a railway locomotive.

During the late autumn manœuvres at Salisbury, one of these engines accompanied the troops and was used for pumping water for the supply of the army. The engine left the railway station drawing a pump behind it, and in two days the pipes were laid to the river, the reservoir was constructed, and water was conveyed to various parts of the camp by troughs. In time of war this operation might be accomplished in less than half that time.

Two of Messrs. Fowler's steam ploughing engines were employed

by the Prussians in the late Franco-Prussian war in transporting guns and war material. The following extract from the "Chemins de Fer pendant la Guerre de 1870-71," par F. Jacqmin, shows that they were successful in hauling heavy material, but were found to be too heavy for the general purposes for which a steam engine is required during the march of an army:—

"Deux machines de route du système Fowler, furent achetées et envoyées à Pont-à-Mousson.

"Un premier train de vivres et fourrages, composé de quatorze voitures et attelé d'une machine, franchit en quinze heures la distance de Pont-à-Mousson à Commercy (quarante kilomètres), sur une route départementale à fortes rampes et à courbes; ce train ramena de Commercy à Pont-à-Mousson huit wagons chargés de pierres.

"Sur de nouveaux ordres de M. de Moltke, les deux locomotives de route amenèrent à Commercy une grosse machine de chemin de fer, système Stroussberg. Après un heureux voyage, elles furent chargées à Commercy sur des trucks de chemins de fer et envoyées à Nanteuil, où elles servirent au transport, par les routes, de grosses pièces de siége prussiennes et des approvisionnements, jusqu'à l'achèvement de la voie provisoire contournant le souterrain de Nanteuil (23 novembre)."

From all the data which can be collected, it may be reasonably assumed that, if the British army should be called upon to take the field, traction engines, specially constructed, could be successfully used by the transport corps; and, considering that the requisite amount of steam power can be kept by Government in reserve, with no further outlay than the interest of the capital invested, the subject of employing steam, to a limited extent, instead of animal power, is worthy of attention at the present time, as horses are becoming yearly more scarce and difficult to obtain.

## Conclusion.

The future of road locomotives must depend to a great extent upon the state of the law with reference to their employment on common highways. As the Act of Parliament at present stands, it is prohibitory to the use of engines upon tramways in towns; it compels the driver of an engine in the country to travel at a very slow speed—not exceeding about 4 miles per hour—and to stop at the request of almost every traveler; and lastly, it makes the owner responsible for all the damage to old bridges, culverts, &c.,

which may result on a public highway during the passage of his engine, even though he may have strictly carried out all the instructions contained in the Act.

In consequence of these restrictions, the haulage of passengers and goods by steam on common roads in England has never been thoroughly developed; but if an equitable law should be passed, passengers will doubtless be conveyed on our present tramways by steam, and the time will soon arrive when a light engine, drawing a couple of cars, will start in the morning and convey residents in the outskirts to their places of business in all cities and large towns, at the rate of 9 miles, or 10 miles per hour, followed by a slower train propelled by smaller engines, and taking up passengers on the road as is now done by the horse cars.

It has been clearly shown that the chief demand for road locomotives existing up to the present time has been for the purposes of agriculture, and that, in spite of all difficulties and obstacles to the use of these machines, the number employed in England has yearly augmented. It is therefore evident that any change in the Road Locomotive Act would benefit the farmer as much, if not more, than any one else; that it would tend to make him more independent in all his operations, and would cause his labourers to become more intelligent, and that thus, by the increased introduction of steam in rural districts, the general prosperity of the country would be advanced.

The Paper is illustrated by a series of drawings and diagrams, from which Plates 11, 12, 13, 14, 15, 16, and 17 have been compiled.

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## I.—Details of Road Locomotives.

[To face page 74.

| Name of Patentee and of Manufacturer. | Description of Engine and Boiler. | Nominal Horse Power. | Number of Cylinders. | Diameter. | Length of Stroke. | Area of Fire Grate. | Number of Tubes. | Diameter of Tubes. | Water Heating Surface per nominal Horse Power of Engine. | Water Heating Surface per Square Foot of Grate surface. | Average Pressure of Steam. | Description of Driving Wheel. | Diameter. | Width. | Ratio of Gearing. | | Advance of Engine per Foot of Piston speed. | | Contents of Tank. | Contents of Coal Bunker. | Weight of Engine ready for Work. | Weight of Engine Empty. | Weight on Driving Wheels. | Weight on Leading Wheels. | Length and Breadth over all. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | Fast Speed. | Slow Speed. | Fast Speed. | Slow Speed. | | | | | | | | |
| | | | | in. | in. | sq. feet. | | in. | square feet. | square feet. | lbs. | | in. | in. | | | ft. | ft. | gallons. | cwts. | tons. cwts. | tons. cwts. | tons. cwts. | tons. cwts. | ft. in. | ft. in. | |
| Gurney | Engine, boiler, and coach, mounted on 5 wheels | 8 | 2 | 8 | 18 | 12·00 | .. | 1¼ | 6·00 | 4·00 | 100 | Rigid, smooth | 60 | 3½ | .. | .. | 5·230 | .. | 60 | 1½ | 3 0 | 3 10 | 2 10 | 1 0 | 22 0 × 6 5 | Passenger engine. |
| Hancock | Engine, boiler, and omnibus mounted on 4 wheels | 10 | 2 | 9 | 12 | 6·00 | .. | .. | 10·00 | 16·60 | 100 | Ditto do. | 48 | 3½ | 2 to 1 | .. | 3·140 | .. | 80 | 2 | 3 0 | 3 12 | 2 12 | 1 0 | 18 0 × 6 5 | Ditto do. |
| Boydell, Manufactured by Charles Burrell | Horizontal engine on locomotive form of boiler. Transmission to driving wheels by spur gearing. Steerage in front | 12 | 2 | 7½ | 12 | 5·50 | 71 | 1⅜ | 22·80 | 40·00 | 100 | Wrought iron, forged all in one piece with tires shrunk on. Rims fitted with Boydell's patent endless railway | 66 | 16 without Shoes. | 8 to 1 | 17 to 1 | 1·070 | 0·500 | 315 | 10 | 9 0 | 11 10 | 8 0 | 3 10 | 17 0 × 7 0 over shoes | For heavy traffic. |
| Bray, Manufactured by Chaplin & Co. | Vertical boiler; horizontal cylinders | 10 | 2 | 7 | 14 | 7·00 | .. | .. | 18·20 | 26·00 | 120 | Wrought iron with sliding spuds | 72 | 15 over Shoes. 6½ on Tire. | 8 to 1 | 16 to 1 | 1·000 | 0·500 | 250 | 10 | 12 0 | 15 0 | 11 0 | 4 0 | 21 0 × 7 3 | Ditto do. |
| Tennant | Locomotive boiler, with horizontal cylinders fixed to the side of the smoke box. Steerage behind | 10 | 2 | 7½ | 10 | 8·25 | .. | 1⅜ | 18·20 | 22·00 | 130 | Wrought-iron rims, fitted with cross straps | 68 | 18 | 6·42 to 1 | 14·7 to 1 | 1·700 | 0·720 | 250 | 10 | 11 0 | 14 0 | 10 0 | 4 0 | 17 6 × 7 6 | Ditto do. |
| R. W. Thomson, 'Colonist' | R. W. Thomson's patent 'pot' boiler, with stoke-hole behind. Horizontal cylinders. Steering gear in front | 8 | 2 | 6 | 10 | 4·00 | 30 | 2⅛ | 12·12 | 24·25 | 140 | Wrought iron, with india-rubber tires | 60 | 16 | 7 to 1 | 14·6 to 1 | 1·580 | 0·660 | 310 | 10 | 5 13 | 7 0 | 5 5 | 1 15 | 14 6 × 7 0 | For fast goods. |
| R. W. Thomson, 'Ravee.' Manufactured by Ransomes, Sims & Head | Hornsby's patent 'Field' boiler, with stoke-hole in front. Vertical cylinders and gearing behind. Steering gear in front | 14 | 2 | 8 | 10 | 11·00 | 218 | 1⅛ | 12·35 | 15·72 | 160 | Ditto do. | 72 | 18¾ | 3·75 to 1 | 12·1 to 1 | 3·060 | 0·920 | 370 | .. | 11 13 | 14 10 | 10 5 | 4 5 | 16 9 × 8 8 | Passenger engine. |
| Head & Thomson, 'Sutherland.' Manufactured by Ransomes, Sims & Head | R. W. Thomson's patent 'pot' boiler. Vertical cylinders and gearing behind. Steering gear in front | 8 | 2 | 6 | 10 | 5·25 | 36 | 2⅛ | 16·98 | 25·88 | 130 | Ditto do. | 60 | 19¼ | 9 · 3 to 1 | 18·4 to 1 | 0·990 | 0·495 | 375 | 12 | 7 10 | 10 5 | 7 10 | 2 15 | 16 9 × 7 9 | For agricultural purposes and goods traffic. |
| Ransomes, Sims and Head | Horizontal engine on locomotive form of boiler. Steering gear behind | 8 | 1 | 9 | 12 | 5·55 | 28 | 2¾ | 18·29 | 26·37 | 70 | Cast-iron rims, with wrought-iron spokes | 60 | 10 | 5 · 8 to 1 | 11·6 to 1 | 1·350 | 0 650 | 150 | 1½ | 8 0 | 9 15 | 7 5 | 2 10 | 16 0 × 8 3 | For agricultural purposes. |
| Charles Burrell | Horizontal engine on locomotive form of boiler, mounted on springs over the hind axle; wheels driven by strong, endless, pitched chains on either side. Steerage in front | 8 | 1 | 9 | 12 | 4·20 | 33 | 2½ | 18·50 | 35·00 | 100 | Cast-iron rims, with wrought-iron diagonal plates, wrought spokes and cast naves | 66 | 14 | 12 to 1 | 18 to 1 | 0·720 | 0·480 | 150 | 8 | 7 10 | 9 0 | 6 10 | 2 10 | 16 0 × 6 4 | Ditto do. |
| Aveling and Porter | Horizontal engine on locomotive form of boiler. Transmission by spur gearing of malleable iron, with compensating gear. Steerage from foot plate | 8 | 1 | 9 | 12 | 4·30 | 30 | 2⅛ | 16·30 | 30·00 | 80 | Wrought-iron rims, with diagonal plates Cast-iron rims and wrought-iron spokes, or Adam's patent elastic wheel | 66 | 12 | .. | 15 to 1 | .. | 0·575 | 160 | 9½ | .. | 7 10 | 5 0 | 2 10 | 16 6 × 6 7 | For agricultural purposes and goods traffic. |
| Ditto do. 'Steam sapper' | Ditto do. | 6 | 1 | 7¾ | 10 | 3·90 | 28 | 2¼ | 16·50 | 25·40 | 80 | Ditto do. | 60 | 10 | .. | 12 to 1 | .. | 0·785 | 110 | 7 | .. | 5 0 | 3 7 | 1 13 | 13 6 × 6 0 | For agricultural purposes, also for transporting war material. |
| J. Fowler & Co. | Horizontal engine on locomotive form of boiler. Transmission by spur gearing of cast steel, with compensating gear. Steerage from foot plate | 8 | 1 | 9 | 12 | .. | 29 | 2½ | 17·13 | .. | 90 | Wrought-iron rims, with diagonal plates, wrought-iron spokes and cast naves, or India-rubber tires, fitted with Greig and Aveling's patent shoes | 66 | 16 | 14 to 1 | 7 to 1 | 0·732 | 0·366 | 200 | 6½ | 7 10 | 9 10 | 7 0 | 2 10 | 16 0 × 7 3 | For goods traffic and agricultural purposes. |
| Ditto do. | Steam ploughing engine, horizontal, engine placed on top of locomotive form of boiler. A drum placed under the boiler for winding the hauling ropes of the ploughs and cultivators | 12 | 1 | 10½ | 12 | 7·60 | 29 | 2¾ | 16·77 | 26·48 | 90 | Wrought-iron rims, with diagonal strips, wrought-iron spokes and cast naves | 66 | 20 | 14 to 1 | 7 to 1 | 0·732 | 0·366 | 180 | 8 | 11 0 | 13 10 | 10 0 | 3 10 | 21 6 × 8 3 | For steam ploughing. |
| Ditto do. | Ditto do. | 20 | 2 | 9 | 12 | 10·00 | 35 | 2¾ | 12·95 | 25·91 | 90 | Ditto do. | 72 | 22 | 14 to 1 | 7 to 1 | 0·732 | 0·366 | 217 | 9½ | 13 10 | 17 0 | 12 0 | 5 0 | 23 9 × 8 8 | Ditto do. |
| Clayton and Shuttleworth | Horizontal engine on locomotive form of boiler. Transmission by spur gearing from the crank, with compensating gear. Steerage in front | 10 | 2 | 7½ | 12 | 5·98 | 34 | 2⅛ | 17·01 | 31·60 | 80 | Wrought-iron arms and tires, with diagonal plates | 69 | 18 | 3·47 to 1 | 5·5 to 1 | 0·820 | 0·517 | 145 | 10 | 9 4 | 10 15 | 6 10 | 4 5 | 19 9 × 7 9 | For agricultural purposes and roundabout steam ploughing tackle. |
| Ditto do. | Ditto do. | 8 | 1 | 9 | 12 | 4·41 | 26 | 2¾ | 17·41 | 31·58 | 80 | Ditto do. | 67 | 15 | 3·66 to 1 | 6 to 1 | 0·775 | 0·473 | 120 | 8½ | 7 17 | 8 15 | 5 5 | 3 10 | 18 6 × 7 5 | For agricultural purposes. |
| Robey & Co. | Horizontal engine on locomotive form of boiler | 8 | 1 | 9¼ | 12 | 5·24 | 30 | 2½ | 17·00 | 26·00 | 100 | Wrought-iron arms and tires, or Mackinder's patent elastic wheel | 64 | 15 | 12 · 2 to 1 | 17·5 to 1 | 1·000 | 0·666 | 100 | 7 | 7 0 | 8 12 | 6 0 | 2 12 | 16 3 × 6 10 | Ditto do. |

## II.—Details of Road Rollers.

| | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aveling. 'Road Roller.' Manufactured by Aveling and Porter | Horizontal engine on locomotive form of boiler. Transmission by spur gearing of malleable iron. Steerage from front or back | 4 | 1 | 6½ | 10 | 3·20 | 24 | 2 | 15·5 | 19·30 | 80 | 4 smooth rollers of cast iron | 56 | 17 | .. | 13 to 1 | .. | 0·676 | 73 | 3½ | .. | 7 10 | 3 15 | 3 15 | 16 0 × 6 0 | For hauling wagons, as well as road rolling. |
| Gellerat. 'Road Roller.' Manufactured by Manning, Wardle & Co. | Horizontal engine on locomotive form of boiler. Transmission by double pitch chain to each roller. Steerage from foot plates | 10 | 2 | 7 | 11 | 4·84 | 51 | 2 | 28·5 | 58·80 | 90 | 2 ditto do. | 47 | 55 | 7 to 1 | .. | 0·960 | .. | 280 | 8 | 12 0 | 15 0 | 15 0 | .. | 17 0 × 6 5 | For road rolling alone. |

III.—Details respecting Street Tramway Locomotives. By Leonard J. Todd, of Leith.

| | Engine for 1 40-passenger car on 1 in 40. | Engine for 2 40-passenger cars on 1 in 40. |
|---|---|---|
| Actual H.P. required at 8 miles on 1 in 40 | 11·1 H.P. | 19·6 H.P. |
| „ „ 10 „ „ 100 | 7·0 „ | 13·0 „ |
| „ „ 10 „ on level | 2·1 „ | 4·3 „ |
| Weight, full | 3½ tons | 5½ tons |
| Driving weight | 2¾ „ | 4½ „ |
| Coefficient of adhesion required on 1 in 40 | ·085 | ·096 |
| Grate surface | 2½ square feet | 3½ square feet |
| Heating „ | 125 „ | 175 „ |
| „ „ per square foot of grate | 50 „ | 50 „ |
| Working pressure | 150 lbs. | 150 lbs. |
| Two cylinders | 5 in. dia. × 9 in. | 6½ in. dia. × 9 in. |
| Single gear | 2¾ to 1 | 3 to 1 |
| Driving wheels, flanged 'Mansell' steel tires | 60 in. dia. × 3 in. | 66 in. dia. × 3 in. |
| Leading wheels, flanged, chilled cast iron | 30 in. dia. × 2¾ in. | 30 in. dia. × 2¾ in. |
| Advance of engine per foot of piston speed | 3·8 ft. | 3·8 ft. |
| Number and diameter of boiler tubes | 45, 1½ in. dia. | 66, 1½ in. dia. |
| Area of tube openings | 48 square inches | 70 square inches |
| Revolutions of crank shaft, at 10 miles | 153 | 153 |
| Water tank, holds | 100 gallons | 160 gallons |
| Coke bunker, holds | 1 cwt. | 2 cwts. |
| Diameter of fan | 10 in. | 12 in. |
| Speed, maximum | 10 miles | 10 miles |
| Wheel base | 5½ ft. | 6 ft. |

IV.—Cost of Haulage by R. W. Thomson's Road Steamer.

The following has been received from Mr. John F. White, of Aberdeen, respecting the performance of his 10-H.P. road steamer, manufactured on R. W. Thomson's patent:—

"I have made careful calculation of the results of the year 1871 (which was the most complete year when I made up my statement) as to the cost of working the 10-H.P. road steamer. I find that the cost per mile per ton was 5*d*. This included heavy outlays for repairs and alterations, and deduction for deterioration of plant. The repairs and changes have been considerable in my case, as some parts were found not sufficiently strong.

"The amount of work done in 1871 was 5,645 tons, wheat or flour, carried 6 miles.

"About a year ago I had a new boiler fitted into my steamer, 'Field's tubular boiler,' which does well. The original boiler was what is called a 'pot boiler.' It did not do well, causing continual annoyance from leakage of the tubes, &c. I have had no trouble with the present boiler."

"P.S. Barring repairs, the work should be done considerably cheaper."

V.—Comparison between the Cost of Haulage by Steam and by Horses.

The following cost of haulage by steam in comparison with horses has been compiled by some farmers in Kent, using Aveling and Porter's 'agricultural locomotive.' It is founded upon the comparative cost of carting 12 tons of material 10 miles, the wagons returning empty. The figures need some rectification to assimilate the prices to those of the present day, although the proportion would probably remain the same.

By Steam:—

*Cost of Plant.*

| | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| 10-H.P. locomotive engine | 420 | 0 | 0 | | | |
| 3 wagons, 6-in. wheels, at £45 | 135 | 0 | 0 | | | |
| | | | | 555 | 0 | 0 |

*Working Expenses per Day.*

| | | | | | | |
|---|---|---|---|---|---|---|
| Coal, 8 cwts. at 1s. | 0 | 8 | 0 | | | |
| Oil, &c. | 0 | 2 | 0 | | | |
| Engine driver | 0 | 5 | 0 | | | |
| Steersman | 0 | 3 | 0 | | | |
| Labourer | 0 | 2 | 6 | | | |
| Wear and tear for 1 day, estimated at 20 per cent. per annum for 250 working days, on £555 | 0 | 9 | 0 | | | |
| Interest on capital for 1 day at 5 per cent. per annum for 250 working days | 0 | 2 | 3 | | | |
| Total | | | | 1 | 11 | 9 |

By Horses:—

*Cost of Plant.*

| | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| 4 teams of horses and harness | 560 | 0 | 0 | | | |
| 4 wagons at £30 | 120 | 0 | 0 | | | |
| | | | | 680 | 0 | 0 |

*Working Expenses per Day.*

| | | | | | | |
|---|---|---|---|---|---|---|
| Keep of 4 teams of horses, including stabling, &c., with wages of 8 men | 2 | 12 | 0 | | | |
| Wagon grease | 0 | 0 | 3 | | | |
| Wear and tear for 1 day, estimated at 10 per cent. per annum for 250 working days, on £680 | 0 | 5 | 5 | | | |
| Interest on capital for 1 day at 5 per cent. per annum for 250 working days | 0 | 2 | 9 | | | |
| Total | | | | 3 | 0 | 5 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Cost of carting 12 tons 10 miles by horse power | £3 | 0 | 5 | or 6*d.* | per ton per mile. | |
| ,, ,, ,, steam power | 1 | 11 | 9 | or 3*d.* | ,, | ,, |
| Difference in favour of steam per day | £1 | 8 | 8 | | | |
| ,, ,, ,, for 250 days | | | | £358 | 6 | 8 |

VI.—Account of Work done by an 8-H.P. Traction Engine on India-rubber Wheels, manufactured by Messrs. J. Fowler and Co., Leeds, and belonging to Messrs. Lister, of the Manningham Mills, near Bradford.

*Cost of Plant.*

| | |
|---|---|
| Engine . . . . . | £651 |
| 2 Wagons . . . . . | 130 |
| | £781 |

*Description of Work performed.*—The work of the engine consists in hauling coal from the Lancashire and Yorkshire coal depôt, Bradford, to Messrs. Lister's mill at Manningham, a traveling distance—in and out—of 5 miles each journey. The load is hauled half that distance—2½ miles each journey—and useful load hauled = 9½ tons. On the journey with the load there is one gradient to ascend of 1 in 20, half a mile long; another of 1 in 12, a quarter of a mile long; and a third of 1 in 40, one mile long; the rest of the road is slightly downhill. 1¼ mile of the road is macadam, the remainder pavement.

| | | |
|---|---|---|
| *Work of one Year* = 261 days at 3 journeys each . . | 783 | |
| 52 „ at 2 „ . . | 104 | |
| | 887 | |
| Deduct for accidents, &c. . . | 37 | |
| Total | 850 | |

The following statement is calculated for the whole year from one month's actual work:—

*Working Expenses.*

| | | | |
|---|---|---|---|
| 1 man at 30*s.* per week . . . . | £78 | 0 | 0 |
| 1 „ at 25*s.* „ . . . . | 65 | 0 | 0 |
| 1 boy at 10*s.* per week . . . . | 26 | 0 | 0 |
| Interest on capital at 5 per cent. (£781) . | 39 | 1 | 0 |
| Depreciation „ 10 per cent. (£781) . | 78 | 2 | 0 |
| Water, 850 journeys at 2*d.* . . . | 7 | 1 | 8 |
| Coke „ at 1*s.* . . . | 42 | 10 | 0 |
| Oil, tallow, and packing . . . . | 11 | 14 | 0 |
| Boy's suit and licence . . . . | 4 | 1 | 0 |
| Repairs at 2½ per cent. (on £781), say . | 20 | 0 | 0 |
| Total cost of carriage of 8,075 tons . . | £371 | 9 | 8 |

= 11*d.* per ton with engine. Cost of haulage per ton per mile = 4·4*d.* With horses, instead of the cost being 11*d.* per ton, it would be 2*s.* 6*d.*

VII.—Account of Work done by an 8-H.P. Traction Engine fitted with Wrought iron Wheels, with Diagonal Strips, manufactured by Messrs. J. Fowler and Co., Leeds, and belonging to the Farnley Iron Company.

*Cost of Plant.*

| | |
|---|---|
| Engine . . . . . | £512 |
| 2 Wagons . . . . . | 170 |
| | £682 |

*Description of Work performed.*—The work of the engine consists in traveling with empty wagons from Farnley Iron Works to Wellington Bridge Depôt, a distance of 3½ miles, and returning loaded with 9 tons of iron-stone. Number of journeys each day, 2. With the load the engine has a gradient to ascend of 1 in 20, 1¾ miles long; the remainder of the road is level.

*Working Expenses per Day.*

| | s. | d. |
|---|---|---|
| 1 man at . . . . . | 4 | 0 |
| 1 „ at . . . . . | 3 | 4 |
| 1 „ at . . . . . | 3 | 4 |
| Oil and tallow . . . . . | 1 | 0 |
| Interest, depreciation, &c. . . . . | 12 | 0 |
| Coal . . . . . | 8 | 0 |
| Total | £1 11 | 8 |

= 1s. 9d. per ton, or 6d. per ton per mile.

The men in charge of the train loaded their own wagons, but if arrangements were made so that the trucks were loaded for them, three journeys per diem could be performed instead of two, which would reduce the cost per ton to 1s. 3½d. against 2s. 8d. per ton, which the work would cost if performed by horses.

---

VIII.—Account of Work done by an 8-H.P. Traction Engine fitted with Wrought-iron Wheels, with Diagonal Strips, manufactured by Messrs. J. Fowler and Co., Leeds, and belonging to the Low Moor Iron Company.

*Cost of Plant.*

| | |
|---|---|
| Engine . . . . . | £512 |
| 4 Wagons . . . . . | 340 |
| | £852 |

*Description of Work performed.*—The work of the engine consists in traveling twice a day from Low Moor to Clifton, a distance of 5 miles, with a load of 10 tons, and bringing back every alternate journey a load of 10 tons; the distance traveled being 20 miles, and gross weight hauled, 30 tons per day. On the outward journey from Low Moor there is a gradient to ascend of 1 in 20, two miles long; the remaining portion of the road is undulating.

*Working Expenses per Day.*

| | s. | d. |
|---|---|---|
| 1 man at . . . . . | 5 | 0 |
| 1 „ at . . . . . | 4 | 0 |
| 1 „ at . . . . . | 3 | 0 |
| Oil, &c. . . . . | 1 | 0 |
| Interest, depreciation, &c., at 25 per cent. . . | 14 | 0 |
| Coal . . . . . | 13 | 0 |
| Total | £2 | 0 0 |

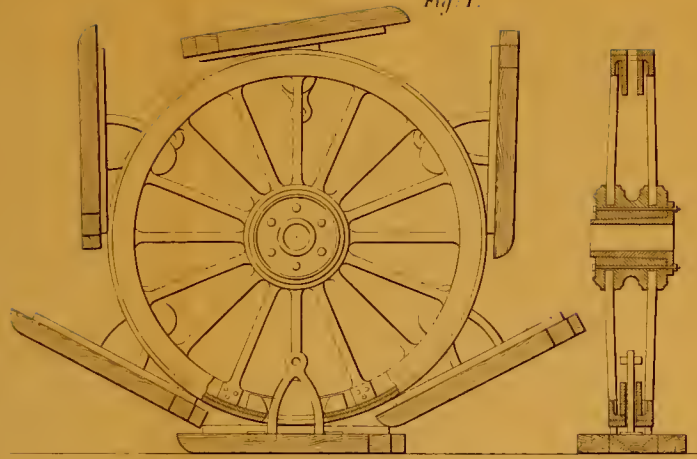
= 1*s.* 4*d.* per ton, or 3·2*d.* per ton per mile.

When working to and from Shelf, a full journey of 5 miles—in and out—three journeys a day are made with a load of 10 tons out and 10 tons in. There is a gradient of 1 in 20 going out, 2 miles long, and another 1 in 10, 30 yards long. The working expenses, including interest, &c., at 25 per cent., and coal, oil, &c., amount to 46*s.* per day, making the cost of haulage = 9*d.* per ton, or 3·6*d.* per ton per mile.

Mr. J. Grantham said, as a model of the steam tramway carriage, constructed under his direction, had been submitted to the Meeting, some explanation in regard to it would probably be acceptable. Several gentlemen being desirous to ascertain whether it was admissible to use steam in streets for the conveyance of passengers, had liberally determined to defray the cost of building a carriage, with which certain experiments had been made in private. It was a common tramway carriage, with power applied from the centre. The experiments had hitherto been satisfactory; and the only question now to be solved was whether it would be objectionable in the open streets. One of the tramway companies had granted permission for the carriage to run on a line, at present not in use, where the public could see it. It had a boiler chamber on each side, and the centre passage was preserved intact. There was nothing peculiar about the engines, and they worked under the seats of the carriage. In hot climates, the car would have a canopy provided for the passengers on the roof. The principal fact to which he desired to draw the attention of the Meeting was that the passengers could pass, without any obstruction, from end to end of the carriage, both inside and out. As was usual with tramway cars, the carriage was not turned, but each end became alternately the back or the front. The handles for working the engine were transferred, the gates were opened and closed, the steps lowered and raised, and all the operations reversed, as usual on horse tramways. He would notice the extent to which the experiments had been carried out. The place in which the carriage was built was under a railway arch, and there was sufficient space for it to run about twice its own length; but that was too limited to give any evidence as to the effect of the steam from the funnel. It had been ascertained that there was no heat perceptible to the passengers inside. There were small mirrors at the end of the chambers containing the boilers, and after the steam had been up for 3 hours, or 4 hours, those mirrors were quite cold. There was no annoyance to passengers from smell or from the motion; and it was also clearly shown that the carriage could be started and stopped with greater ease and rapidity than when horses were employed. He hoped shortly to have an opportunity of placing it on a tramway where it could be seen by the public.

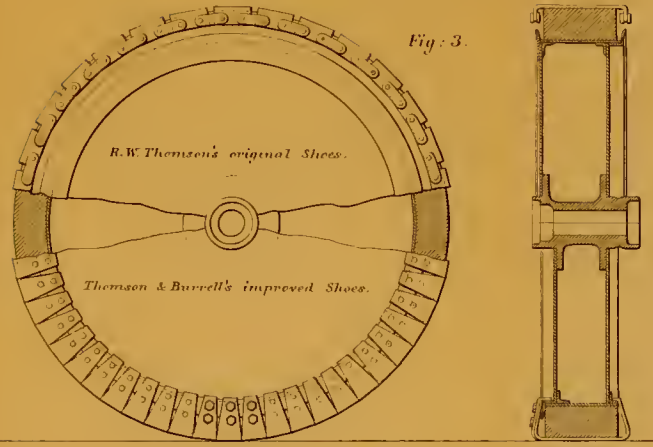
Mr. T. Aveling said, the cast-iron wheels of the engine referred to in the Paper as having been tried at Wolverhampton, and as having drawn $3\frac{1}{2}$ times its weight, had no cross bars upon them. The bearing surface of the wheel on the road was perfectly smooth. If the engine had been fitted with cross bars, as wheels were fitted

Fig. 1.



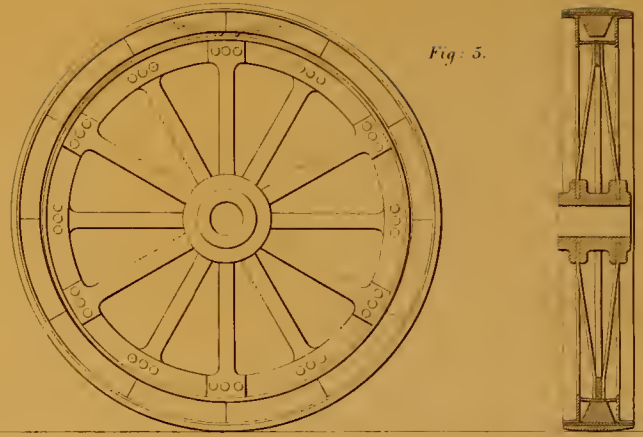
BOYDELL'S WHEEL. CHARLES BURRELL, THETFORD.

Fig. 3.



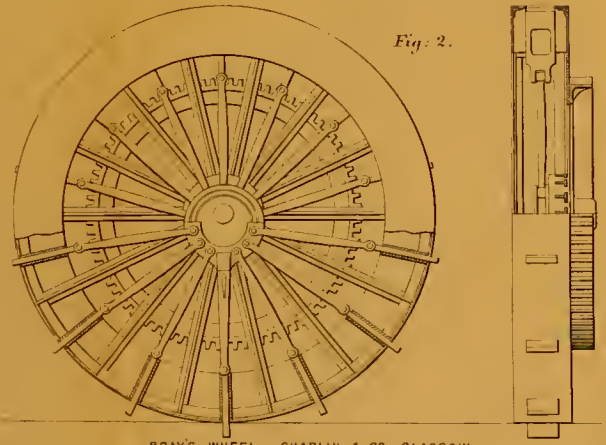

R.W. THOMSON'S INDIA RUBBER WHEEL.

Fig. 5.



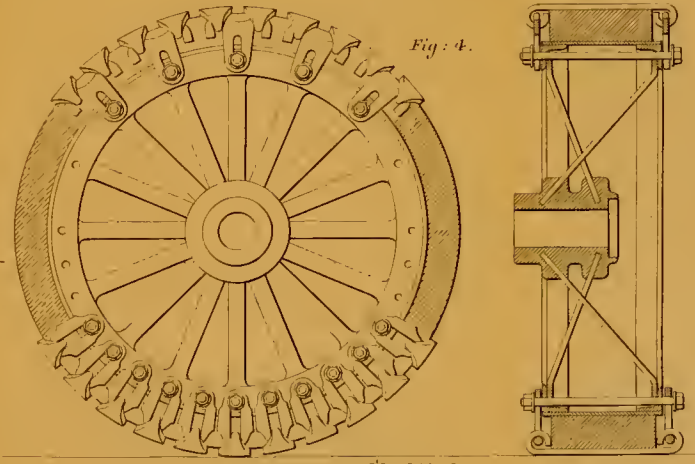
ADAMS' WHEEL. AVELING & PORTER. ROCHESTER.

Fig. 2.



BRAY'S WHEEL. CHAPLIN & CO. GLASGOW.

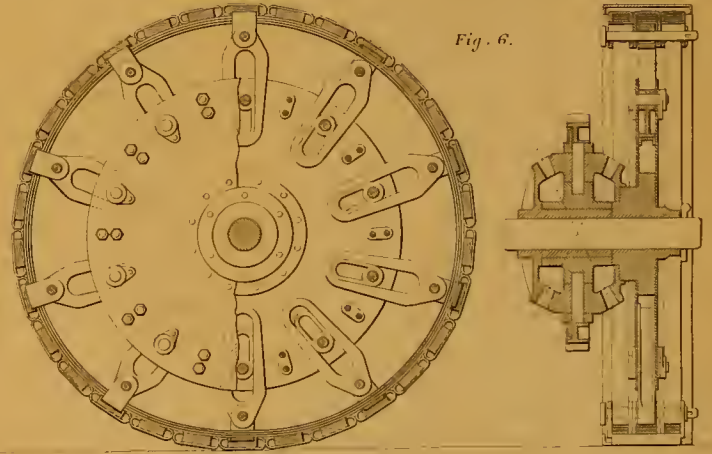
Fig. 4.



CREIG & AVELING'S SHOES.

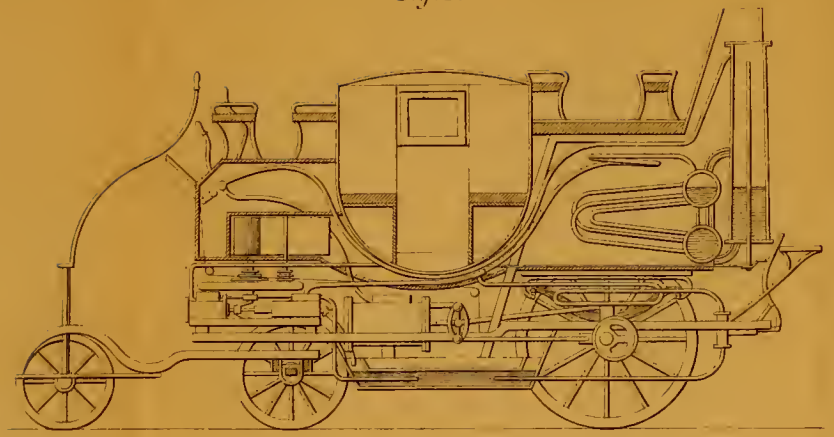
Scale of Feet

Fig. 6.



BREMME'S FLEXIBLE STEEL WHEEL.

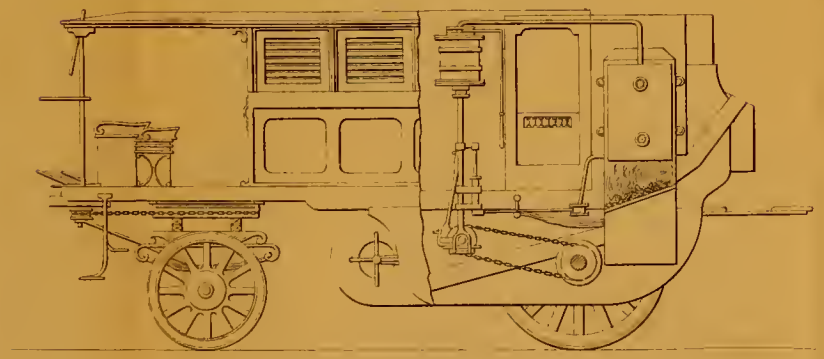
*Fig: 1.*



GURNEY'S STEAM COACH. 1828.

*Scale of Feet.*

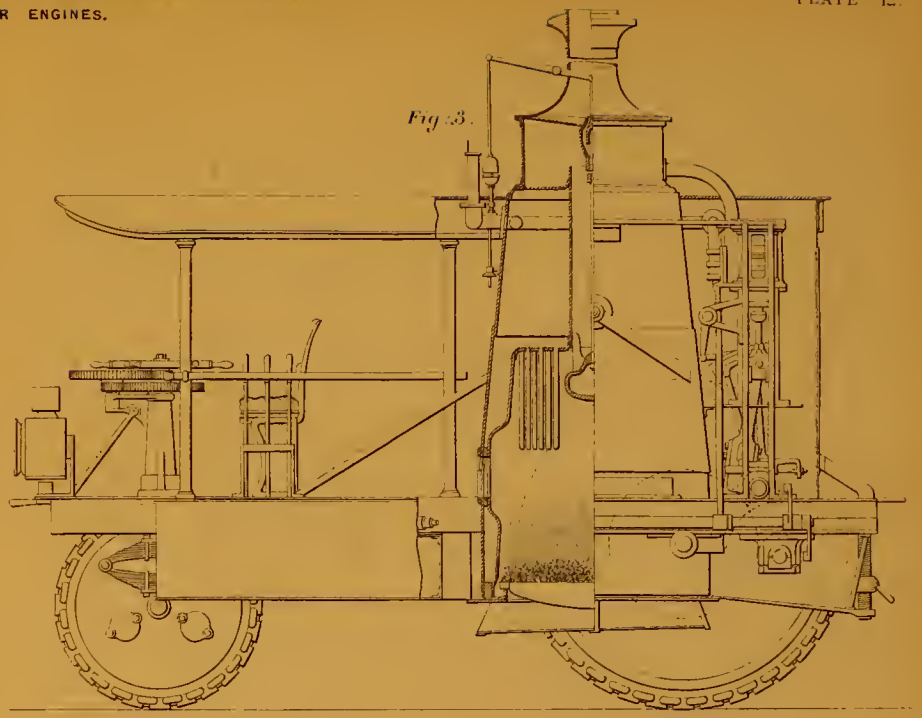
*Fig: 2.*

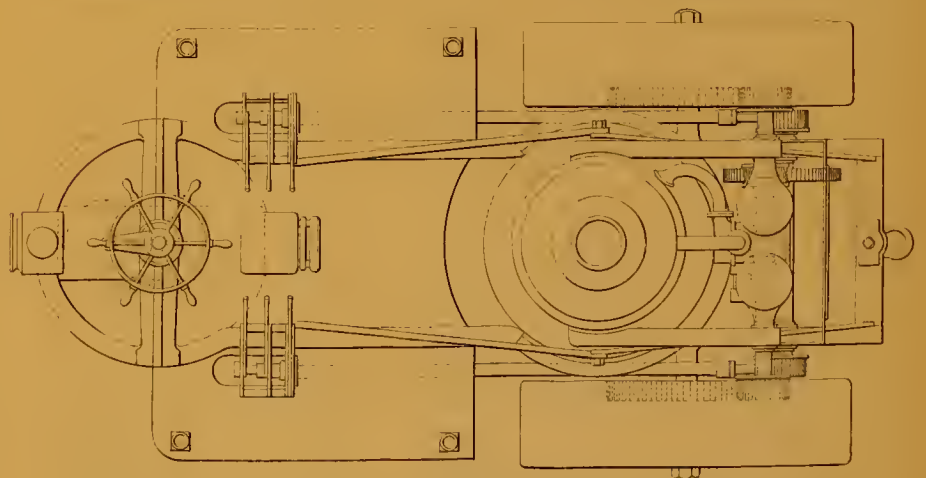


HANCOCK'S STEAM OMNIBUS. 1833.

*Scale of Feet.*

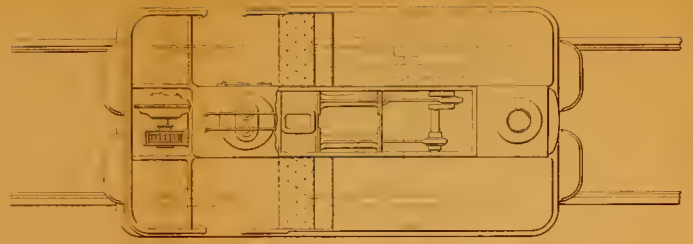
*Fig: 3.*





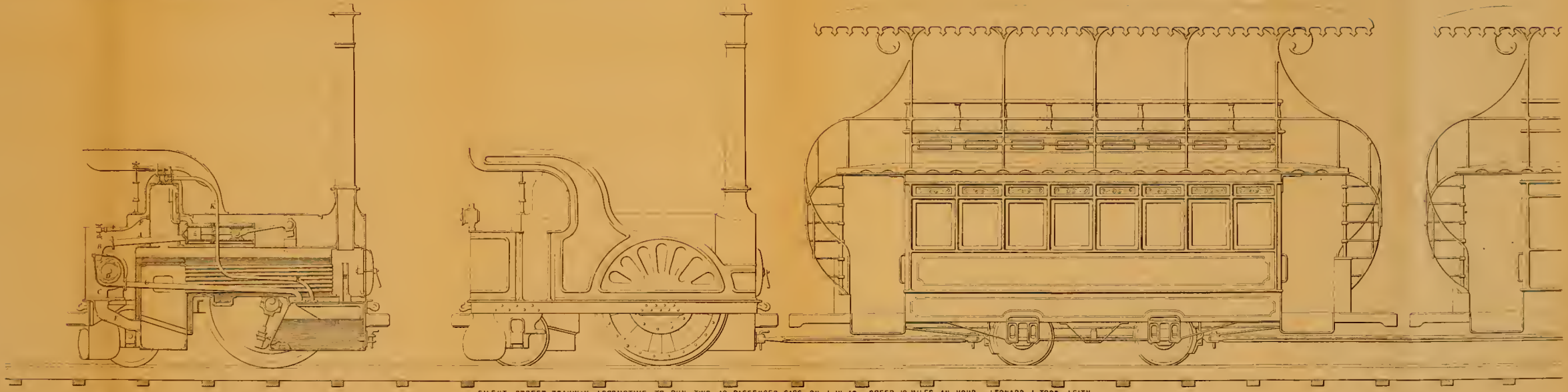
R.W. THOMSON'S 14 H.P. ENGINE "RAVEE" FOR H.M. INDIAN GOVERNMENT. RANSOMES, SIMS & HEAD.

*Scale of Feet.*



REFERENCES.

A Exhaust from Cylinder
B Adjustable Nozzle
C Silent Blowing Fan
D Bucket Wheel
E Air Pipe to close Ash Pan
F Pipe to run Fan when Engine is standing
G Exhaust from Fan to Tank
H Superheated Steam from Tank
K Escape from Safety Valves to Tank



SILENT STREET-TRAMWAY LOCOMOTIVE, TO RUN TWO 40-PASSENGER CARS ON 1 IN 40; SPEED 10 MILES AN HOUR. LEONARD J. TODD, LEITH.

Scale of Feet.

# STEAM LOCOMOTION ON COMMON ROADS.

## ENGINES FOR GOODS AND HEAVY TRAFFIC.

*Fig. 1.*

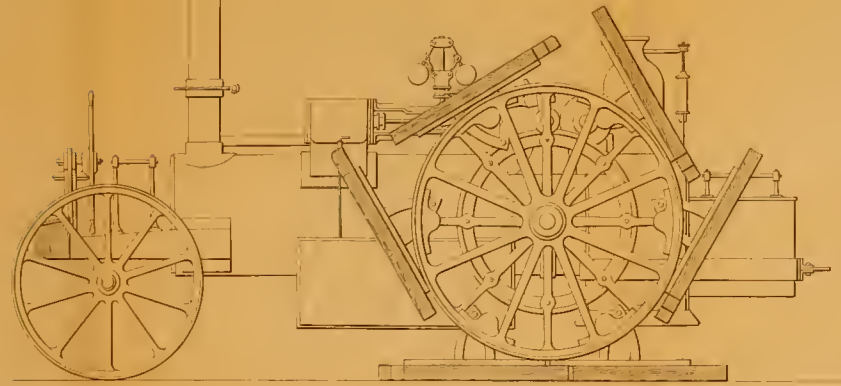


*Fig. 2.*

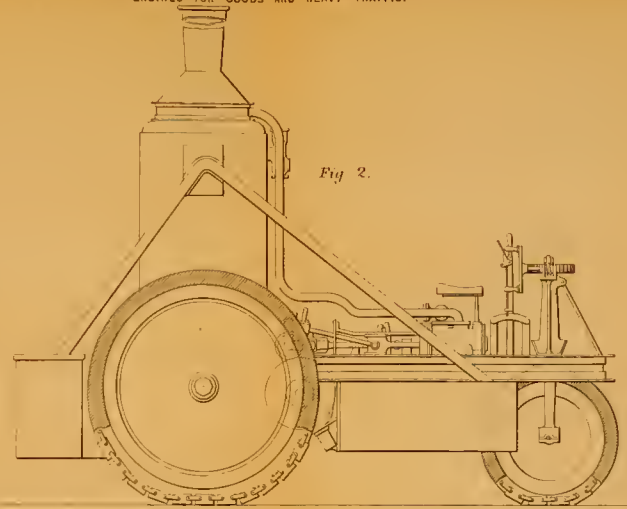
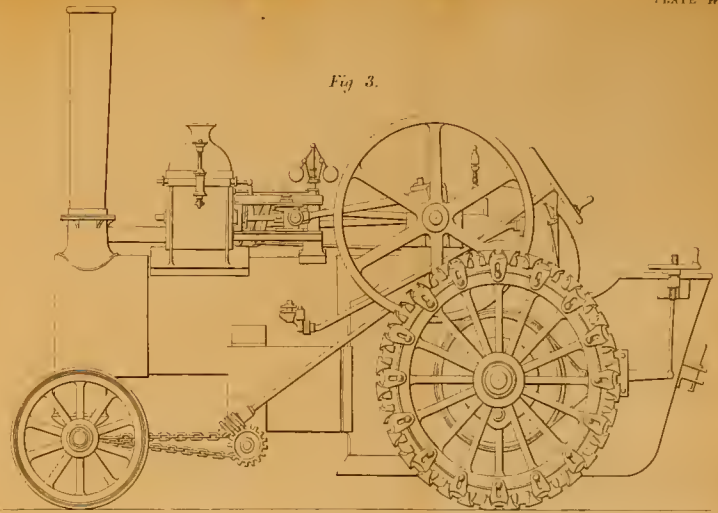
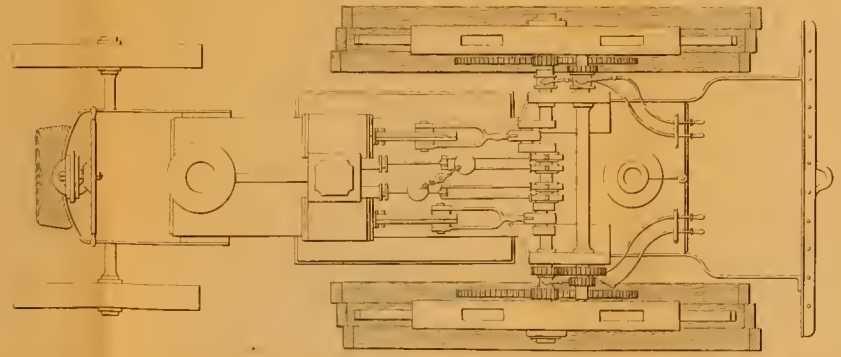
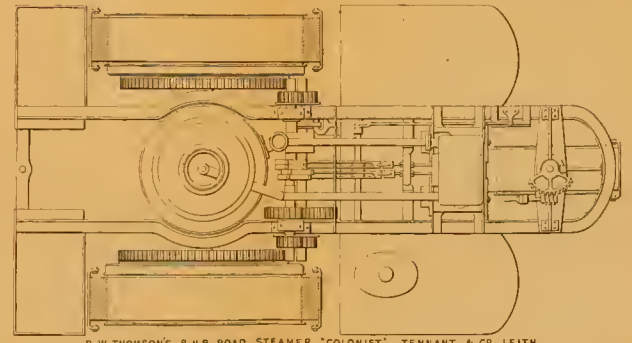


*Fig 3.*



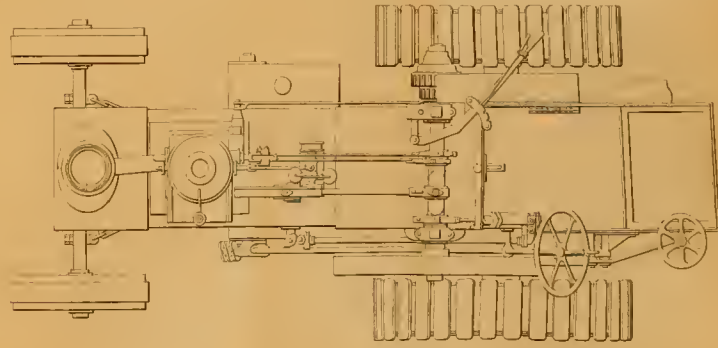


BOYDELL'S 12 H.P. ENGINE. CHARLES BURRELL, THETFORD.



R. W THOMSON'S 8 H.P. ROAD STEAMER "COLONIST" TENNANT & Co LEITH.

Scale ½ Inch 1 Foot



8 H.P ROAD LOCOMOTIVE. FITTED WITH INDIA RUBBER TYRES. JOHN FOWLER & Co LEEDS.

*Fig: 1.*

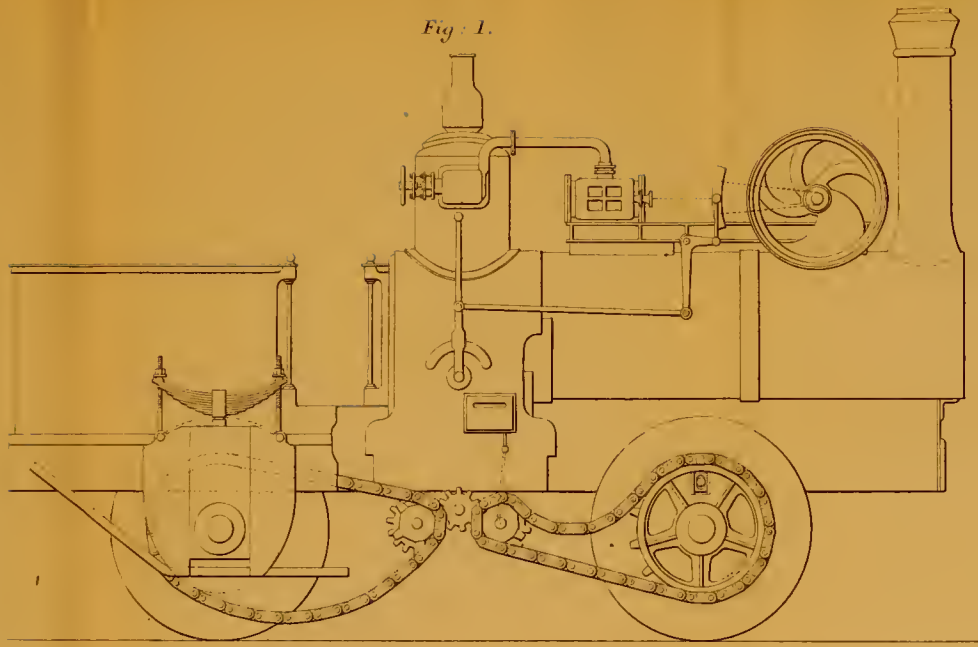
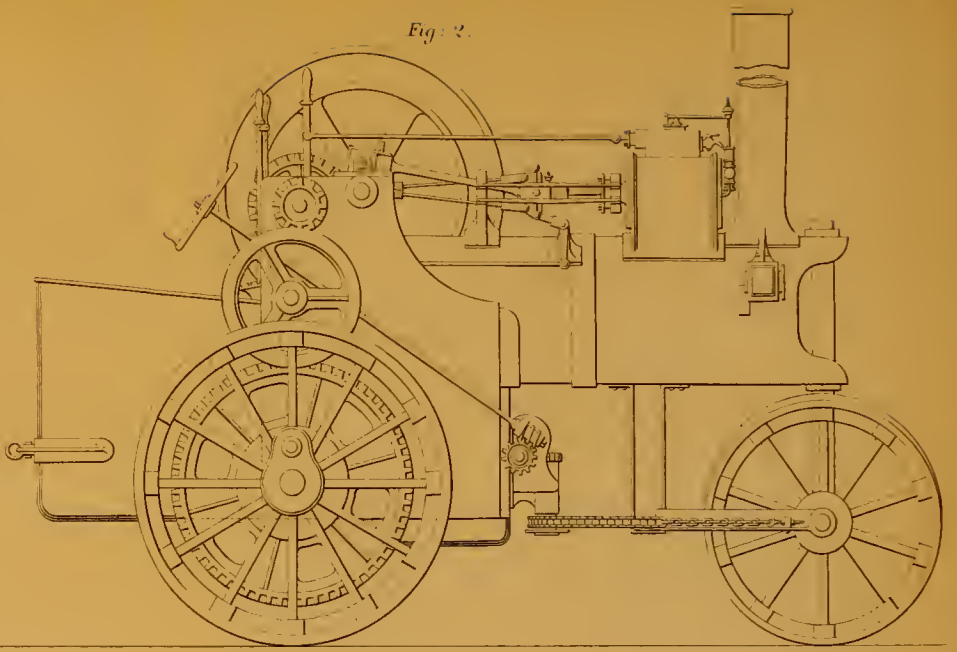
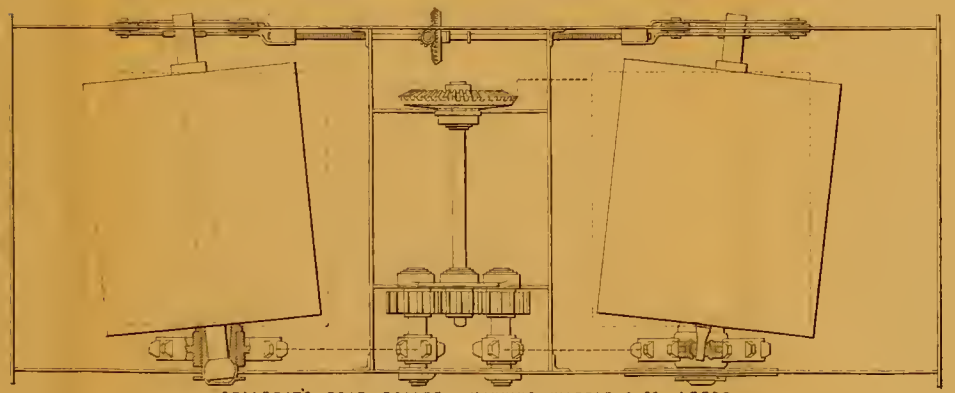


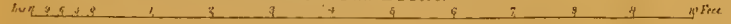
*Fig: 2.*

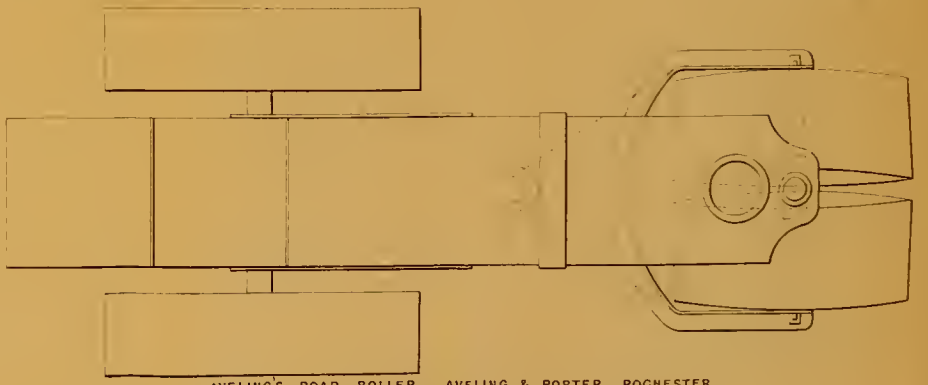




GELLERAT'S ROAD ROLLER. MANNING WARDLE & Cº, LEEDS.

*Scale ⅜ Inch = 1 Foot.*

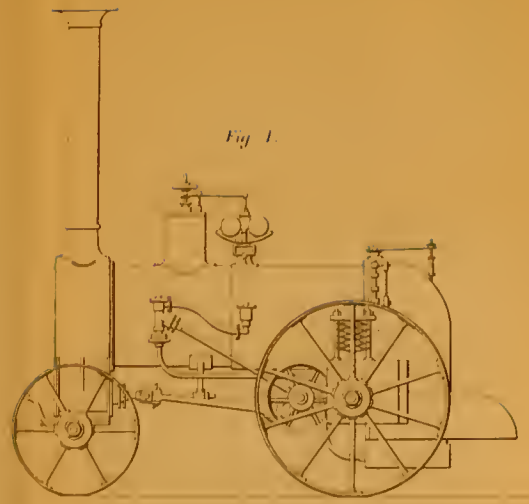


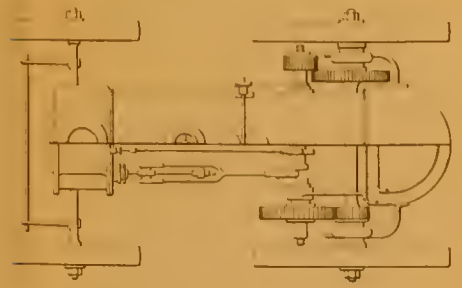


AVELING'S ROAD ROLLER. AVELING & PORTER, ROCHESTER.

*Scale ⅜ Inch = 1 Foot*

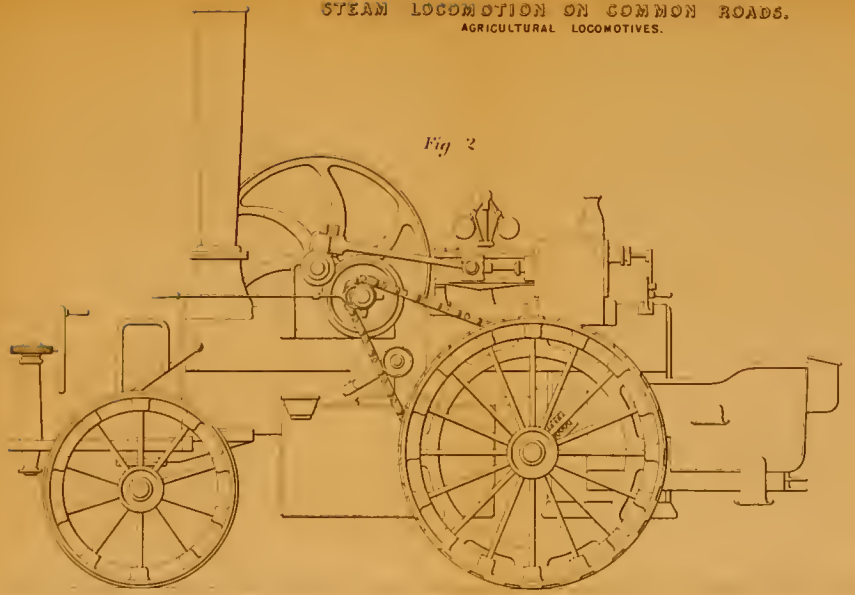
*Fig 1.*

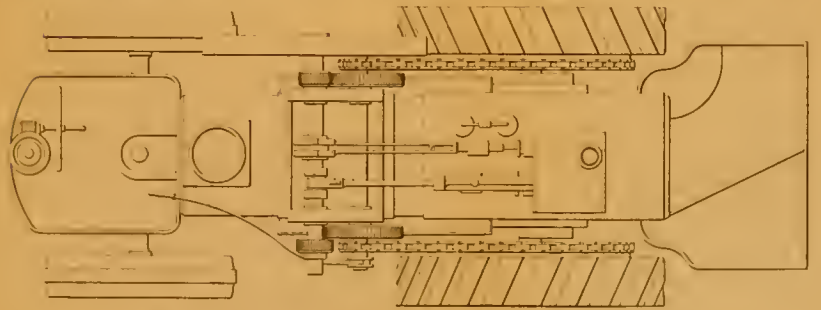




6 H.P AGRICULTURAL LOCOMOTIVE. EXHIBITED AT NORWICH IN 1849. RANSOMES AND MAY. IPSWICH

*Fig 2*

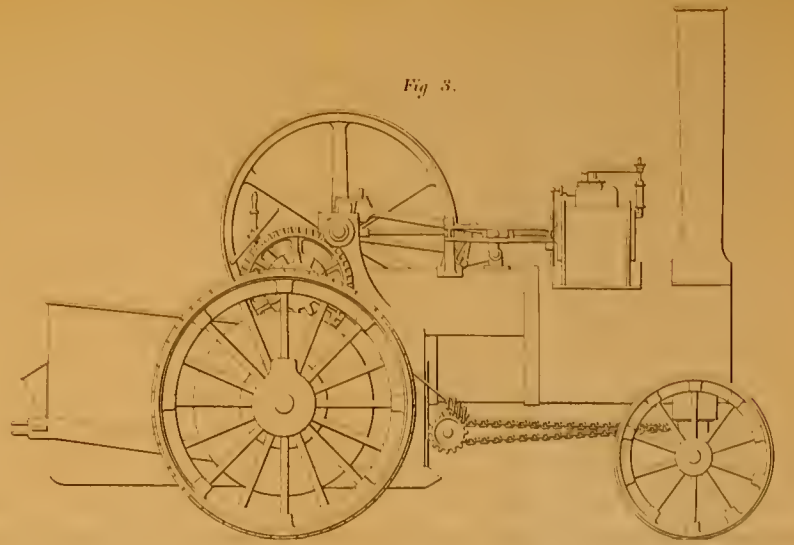


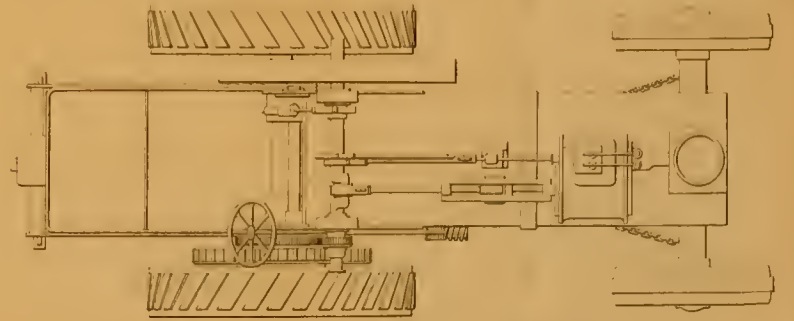


8 H.P AGRICULTURAL LOCOMOTIVE. DRIVEN BY A PITCH CHAIN. CHARLES BURRELL. THETFORD.

*Scale 1 Feet*

*Fig 3.*

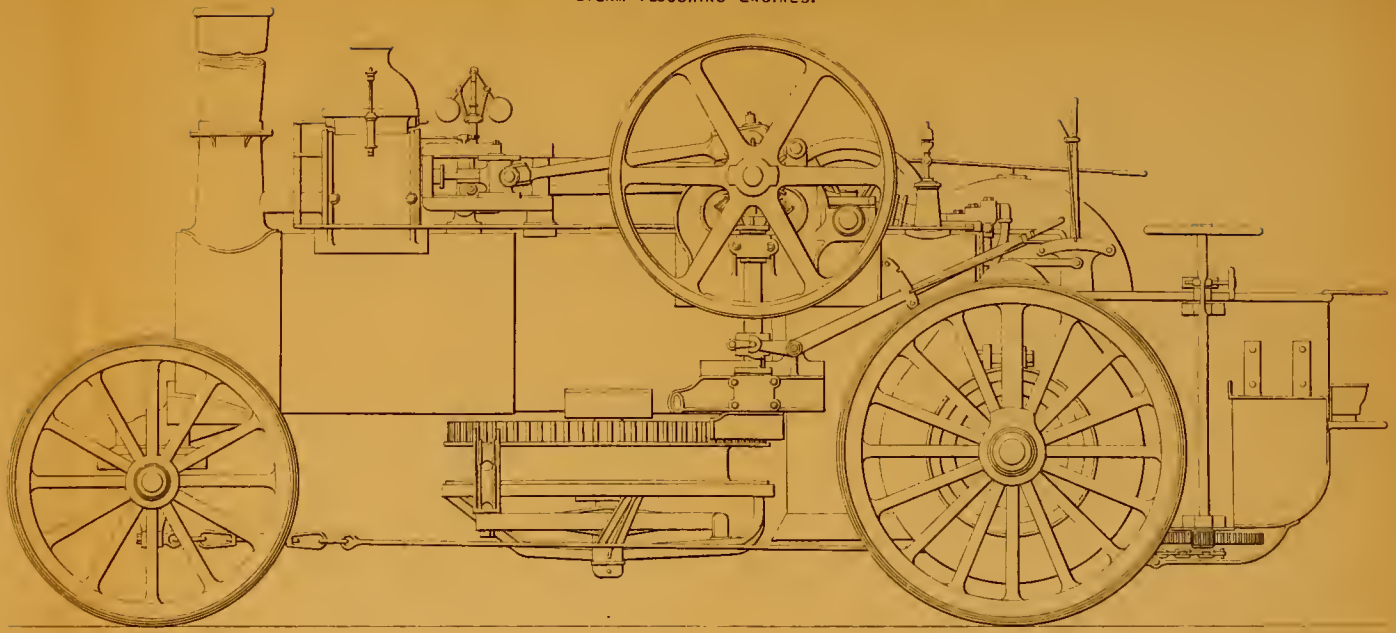


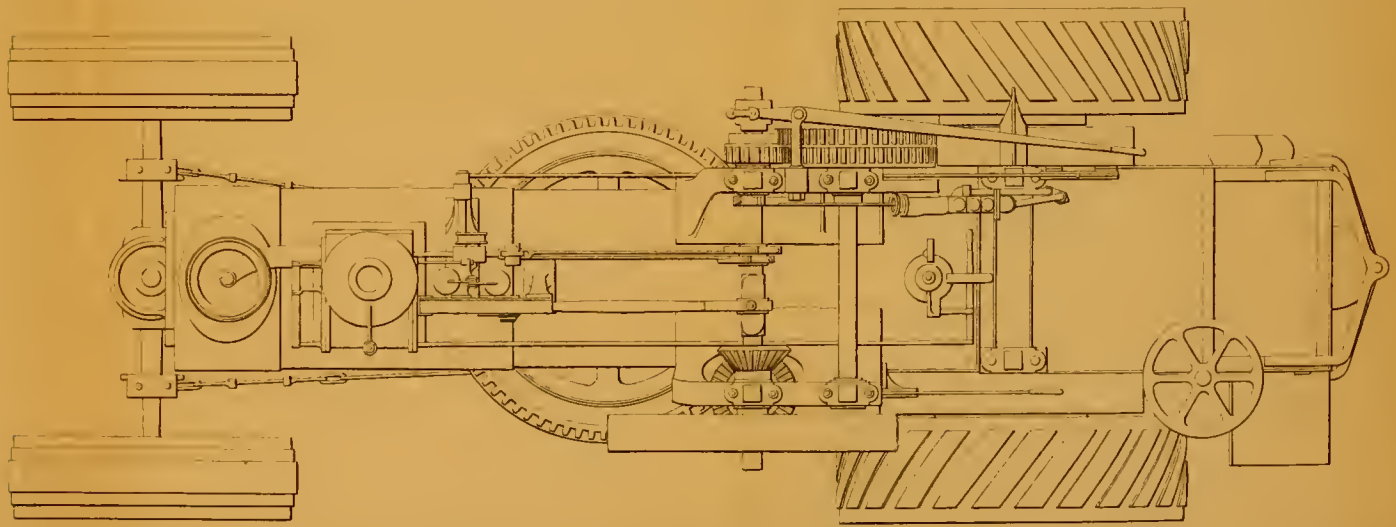


8 H.P AGRICULTURAL LOCOMOTIVE. AVELING & PORTER. ROCHESTER

# STEAM LOCOMOTION ON COMMON ROADS.

## STEAM PLOUGHING ENGINES.





12 H.P. STEAM PLOUGHING ENGINE. JOHN FOWLER & Co LEEDS.

Scale 3/8 Inch = 1 Foot.

0 1 2 3 4 5 6 7 8 9 10 Feet

J. HEAD. DELT.

Minutes of Proceedings of The Institution of Civil Engineers Vol XXXV Session 1872-73.

BELL BROS LITH LONDON

for locomotive purposes, it would have nearly approached—as it had since—the tractive power of the india-rubber tires fitted with cross-bars. He agreed as to the great advantage derived from the use of india-rubber tires upon paved roads. In fact, it was an extremely difficult matter to draw a load on a pavement with a rigid wheel, but on macadamised roads its performance was satisfactory. There was, however, so much expense attending the use of flexible tires, that the benefits obtained from them must be much greater than had yet been shown before their general adoption would be warranted.

A pair of elastic wheels on Adams' system had been made by Messrs. Aveling and Porter for one of Mr. Neville Granville's engines. Mr. Aveling had been told that they had run 500 miles; but it was difficult to keep the outer tire and the inner tire coupled together. The action of the wheel, as far as making it more comfortable for the driver, was no doubt an improvement. The engine could also draw more with wheels fitted in that manner on paved roads, because the contact was more certain at all times. The wheel did not jump from one stone to another; but nevertheless he was not satisfied with that description of wheel. He might add, he had lately tried experiments with spring tires and rigid tires on good macadamised roads, and he had never found that a wheel which flattened itself on the surface of the road could draw the load with the same pressure of steam as a rigid wheel fitted with wrought-iron cross bars. The flexible wheel would require from 6 lbs. to 8 lbs. more steam pressure. On the whole he considered the 'rigid' system to be preferable to the 'flexible' system.

Mr. L. J. Todd considered that if steam tramway locomotion was to be successfully carried on it must be done by a separate engine drawing a car. Any combination of the boiler and machinery with the passenger carriage — like the successive attempts made by Gurney, Hancock, and Scott Russell, in Great Britain, and by Remington, Baxter, and others, in the United States — would prove, more or less, unsuccessful. It would be dangerous to run the car referred to by Mr. Grantham in the streets, as it had two boilers shut up in small spaces, in which the driver could not see what was going on. Supposing it was running on a dark night, and the driver happened to be a little intoxicated, an explosion would probably take place. The passenger engine called the 'Pioneer,' tried in Edinburgh a year or two since, was similarly constructed. It had a single boiler at one end of the car, and below the floor three cylinders coupled to one pair of the wheels; and from the mud and dust it was found impossible to keep the

working parts in order when running on common roads—even on those in the best condition—so that in three months, or four months, the whole of the joints and brasses had to be renewed. Again, if the engines were placed below the car, and there was the slightest escape of steam from the glands, it would rise through the floor of the carriage and frighten the passengers, especially if they were ladies. On one occasion the exhaust pipe of the 'Pioneer' burst, when it was taking out the Town Council of Leith for a trip, who, when they saw the steam issuing through the floor, very speedily 'cleared out' and ran off for some distance. That was an accident; but even a little steam coming up from the glands through the floor would frighten ladies in such a way that they would not travel in the car at all. The canopy for the outside passengers alluded to by Mr. Grantham would always be required, as with a short funnel coming up through the roof in the midst of them it would be impossible they could otherwise be kept free from smoke and soot. In the 'Pioneer,' the smoke was carried off at the rear of the carriage by an opening at an angle of 45°, so as to discharge the dust and steam behind, and yet it was found impossible to keep the roof seats clean, and the fireman at the end of each run had to go up and sweep the dirt away. Then, again, in the matter of repairs. It was better to work at an engine in a shop into which it could be taken by itself, and where it would be apart from the passenger car. With the 'Pioneer,' it was found that the fittings of the passenger carriage were very much damaged by the smoke and dirt of the repairing shop; and it would have been much better if the engine could have been repaired by itself, and the carriage have been left free for service. Mr. Todd would repeat that the worst feature of the carriage described by Mr. Grantham was the enclosure of the two boilers in places where they could not be easily inspected, as such an arrangement must sooner or later be the occasion of an accident.

Mr. Bramwell said, the subject of which the Paper treated was one of great interest to him, and had been so ever since his apprenticeship, when he became acquainted with the well known Walter Hancock, the most successful maker of common road locomotives, and was frequently with him at his manufactory at Stratford.

The scope of the Paper was very extensive. It included the self-propelling passenger carriage for high speeds; the high speed traction engine; the slow speed traction engine for goods; the self-moving engines for ploughing, and for other agricultural purposes; the self-moving tramway car, or the traction engine for

such cars; and it also included steam road rollers. It thus opened out a wide field of discussion; but Mr. Bramwell would not weary the Meeting by attempting even to touch upon the whole of those matters, but would confine his remarks almost entirely to one division, namely, to the quick traveling, self-propelling passenger coaches. The Author alluded to the names of Gurney and Hancock, but there were other names which might be mentioned, such as Ogle, Maceroni, Dance, and Church.

With the exception of the steam ploughing locomotive, which was worked in the field, and not upon roads, and the steam roller commonly used on roads which were for the time closed against horse traffic, the question whether or not locomotives could be employed on common roads depended in a great measure upon whether or not horses would be frightened by them. Mr. Hancock for many months used to run his steam carriage regularly from Paddington to the Bank and back, and in the other direction from Cornhill to Whitechapel, among the ordinary omnibuses. For the first week or two after the steam omnibus started the horses along the road showed signs of inquietude, but after the running had continued about a fortnight the ordinary omnibus horses on the road paid no attention to the steam. When strange horses went by there was frequently some sign of restlessness, but not much. Mr. Bramwell thought a great deal of this indifference on the part of the horses to Hancock's steam coach arose from the care which had been taken to make it in a shape that should be "reasonably agreeable" to horses. One of Hancock's earliest steam carriages was called the 'Infant.' Some years after its construction he built another and larger carriage, called the 'Automaton,' of the same general form; another, called the 'Era,' which had an ordinary coach body; and another, called the 'Autopsy,' with an omnibus body. All those were built more or less like ordinary coaches and omnibuses, and, being so, they did not appear to offend the susceptibilities of the horses. Further, Mr. Hancock took care that there should be no moving machinery visible. With the exception of the driving wheels there was not a particle of moving machinery to be seen; and there was no smoke, because coke was used; neither was there any noise. The waste steam was blown into a box, and issued by a number of holes into the fire, and escaped quietly, and any steam from the safety-valves was dealt with in the same manner. In that way the steam coaches passed along, and neither by the sight of moving machinery, nor by the sounds of waste or escaping steam, did they cause alarm. Mr. Bramwell thought, if similar care were taken in

the present day to conceal the moving machinery, and if the noise of exhaust steam and that of steam whistles were dispensed with, there would be little if any trouble with regard to horses.

Further, in his opinion, after the engineer had paid all the attention he could, to make the construction of those engines as little offensive as possible, the matter was one of such importance that—if horses were still to some extent alarmed—the proper course would be not to settle the question by forbidding the use of such engines on common roads, but to solve it by educating horses to pass steam carriages without being frightened by them, as they were now educated to pass military bands and railway bridges, or to pass other things which were sources of annoyance. It was well known that horses about railway stations paid no more attention to a locomotive than to another horse alongside them. There would be no difficulty in thus training horses if it were worth while—and he thought it was.

Mr. Bramwell believed that Mr. Hancock, between 1830 and 1840, did more to show what was practicable on common roads with steam locomotives than any other person had done before or since. In each of Hancock's carriages the engine was in one with the body of the coach, but the objections to that mode of construction which had been raised by Mr. Todd did not apply, inasmuch as the boiler was placed at the hinder part of the coach. The engine was in a separate room. The water-tanks were placed under the passengers' seats; and the blowing-fan was under the ash-pit. The boiler, the soul of such machinery, was ingeniously constructed. It was stated in the Paper that:—"The boiler was about 2 ft. square and 3 ft. high, and was made with flat chambers, 2 in. wide and $\frac{1}{8}$ in. thick, covered with bosses, arranged in such a manner that the bosses of one chamber touched the bosses of the neighbouring chamber, thus forming abutments, and at the same time increasing the heating surface."[1] It was rather an inaccurate phrase to say that the boiler was made with chambers, for the chambers formed the boiler. The principle on which each chamber was made was very simple, namely, the same principle as that on which an ordinary biscuit-bag was made. The sheet of iron was bent in the middle until the two portions were brought parallel, the one to the other, in the same way that a sheet of paper was folded to make the two sides of a bag; then the edges of the sheet of iron were brought together, and were united by being riveted up the two edges and along the top. Thus there were no rivets at the

[1] *Vide* ante, p. 48.

bottom of the chamber—the part which was placed immediately over the fire. In that way there was formed a flat chamber 2 in. wide; a number of those were put side by side, with spaces between each; the spaces were also about 2 in. wide, and through those spaces the fire played. Evidently no form could be more improper for withstanding a high pressure of steam than that of a flat chamber, but Mr. Hancock got over the difficulty in the following manner:—The sides of the chambers were covered with hemispherical bosses, and when the chambers were put together side by side the summits of the hemispheres—if he might use the word summit to a hemisphere—impinged one upon the other, and thus every chamber was the support of the chamber on each side of it. In this way the boiler was self-supporting until the two outside chambers were reached; those required further support. That was given by a thick wrought-iron plate the full size of the outside chambers which bore on their hemispheres; outside those plates strong girders were put in three places, and bolts outside the chambers passed through the ends of the girders and braced the boiler together, aided by two other tie-bolts, which passed, one along the lower part, and the other along the upper part of the boiler. In the centre of each chamber there was a vertical plane raised to the same height as the hemispherical bosses, so that when the chambers were placed together those raised planes nearly touched each other from top to bottom all the way down the middle. Further, there were introduced into each of the chambers two rings of gun-metal as wide as the chambers in those raised parts were broad, namely, about 4 in.; those rings had a number of small holes passing radially through their circumferences, while through the large central hole passed one of the tie-bolts; that bolt was much smaller than the central hole, and thus there was an annular space between the outside of the tie-bolt and the inside of the ring. Then there was a ring of copper wire between each chamber, and pressure being applied by the bolts, the whole was screwed up tight. Thus not only was the boiler held together by those bolts and ring washers, but they formed an annular tube at the bottom and another at the top, the bottom one serving as the feed tube to all the chambers, and the top one as a steam-pipe from all the chambers.

Other matters worthy of notice were considered by Mr. Hancock. One was that instead of placing the driving wheels direct upon the crank shaft he placed them upon a separate straight axle driven from the crank shaft by means of a chain and pitched pulley. The relative distance between the two shafts was always, notwith-

standing any rise or fall, preserved by horizontal radius rods. That enabled him to use perfect carriage-springs for the driving wheels without interfering with the action of the crank shaft of the engine. In those days neither donkey engines nor injectors were known, and thus driving as a second motion afforded great facility for working feed-pumps when the coach was not running. All that was necessary was to throw out the clutch from the chain pulley, and then the engine could be worked as might be desired for the purposes of pumping, or of urging the fire by the fan-blast.

The wheels were not rigidly attached to their driving axle, but were loose upon it, and were worked by clutches. Those clutches had a large amount of clearance; so that the carriage, when steered on any short easy curve to pass another carriage, could obey the steersman with facility, because the driving wheel which was on the outer side of the curve could overrun its driving clutch, and thus keep true pace with that of the inner wheel. Moreover, when it was required to turn the coach in its own length, that was effected by throwing out of gear the clutch of one of the wheels, which then became the pivot on which the coach turned.

There was another question which was worthy of notice—that was, with respect to the fire bars. Two sets, coupled up, were provided, and were so arranged that when one set were slid into the fire the other was outside; thus when one set of bars became clinkered they could be withdrawn, and another clear set could be put in, and when the clinkers were scaled off the first lot of bars they were ready to be put in again. The steering arrangement also was well thought out: it consisted of a chain and wheel; and the peculiarity was that the driver, with a pedal, could hold the fore wheels in any required position without strain on his hands, which were only employed when the pedal was relieved preparatory to its being required to alter the direction of the carriage.

Much had been said in the Paper in reference to the great trouble of road locomotives—the driving wheels. That trouble was no new one; for Mr. Bramwell remembered Mr. Hancock had said to him:—"You will be surprised to hear that the point in which I found most trouble is one that seems the most simple: that is, in the tire of the driving wheels, owing to their great wear." In Hancock's carriages the wheels were made of wood. As regards their felloes and spokes, which had radiating ends secured into cast-iron plate bosses, although the spokes were straight, that

is, were not 'dished' at all, the material — wood — afforded a certain amount of elasticity, which enabled the wheels to stand the work for many months. It should, however, be borne in mind that the engine was not one of those ponderous machines which were now employed for traction on common roads, weighing from 8 tons to 11 tons. For instance, the weight of the 'Infant' was only about $3\frac{1}{2}$ tons, although it conveyed 16 passengers, besides the steersman.

Mr. Bramwell thought that, of late, sufficient attention had not been paid, in the science of common road locomotives, to the possibility of making light engines. With such engines of course the power to draw heavy loads could not be obtained, but for passenger carriages containing the motive power within them, where there was nothing but the load of the vehicle and of the passengers to propel, there was every inducement to make the weight as small as possible. It must be remembered that although greater weight gave greater adhesion it required greater power, and greater power required greater weight, so that the increase might go on indefinitely, as in the contest between big guns and thick armour plates. That the great weight was not necessary for quick passenger traffic they knew from Mr. Hancock's experience. Neither was great weight a necessary accompaniment of great power. On this point he would wish to instance that which Mr. Thorneycroft had done in engines for river navigation. He had produced 70 I.H.P., with a weight of only 4,900 lbs., including the water in the boiler and the weight of the propeller, with its shaft. Those who had devoted attention to the subject would bear Mr. Bramwell out in the statement that light engines could be made, and he was certain when that was done the great destruction of the wheels spoken of in the Paper would not take place.

He would mention that Mr. Hancock was one of the first to discover that the way to keep the boiler from priming was to cause the steam to come through an extremely small steam-pipe—namely, $1\frac{1}{4}$-in. steam-pipe for a pair of 10 in. cylinders in the 'Automaton;' and he was one of the first to use the eccentric rod with inclined horns and a 'gab' on each side to get reversal of motion. The ability and skill showed by Mr. Hancock in the mechanism of his common road steam coaches so long ago as 1835 would do credit to the most talented Engineer of the present day.

With respect to traction engines, the Author had shown the effect of putting the load upon an india-rubber tire, namely, that it threw out the tire in advance of the wheel, and that it caused the tire to assume different thicknesses in different parts. On reflec-

tion it might be perceived that the action of a load upon such a tire advancing over a surface was very much that of a rolling mill, and that the tire was being thinned at the part below the middle of the wheel. This of necessity forced out the accumulation in front, and caused the tire to slip round to bring the material again into its proper position. Mr. Bramwell must say he had entertained a very high opinion of those india-rubber tires, first, because they appeared to afford a spring in the place where the spring was best situated; that was, in the nearest point to the road; and, second, because of the great adhesion they gave on paved and on other road surfaces. He feared, however, the elasticity of those tires was not perfect, and that they absorbed power in the continuous change of form. He was led to that conclusion by the fact, that, after some amount of working, there was a considerable generation of heat within the substance of the tire, which was indicative of work put into it, and was inconsistent with perfect elasticity. That development of heat was accompanied by a strong smell of sulphur. As to the great powers of traction possessed by india-rubber tires upon ordinary roads there could be no doubt.

The Author had alluded to some experiments made by Mr. J. Easton and by Mr. Bramwell, in which, fortunately, they were able to try the very same carriage with india-rubber tires and with plain cast-iron wheels. They also tried them in competition with another traction engine which had cast wheels, with a sort of cellular pattern on the tread—not with ribs across, as was stated in the Paper. On good hard road the proportions were:—for india-rubber, a tractive force of 45 per cent. of the insistent weight; for cast-iron wheels, with a cellular pattern on their treads, 35 per cent.; and for small smooth-faced cast-iron wheels, 25 per cent. No doubt on ordinary roads the india-rubber had great advantage in tractive force, but when those engines were used on wet land the conditions were not so favourable for india-rubber. The same engines had been tried over a farm after 24 hours' very heavy rain, and then the cast-iron wheels succeeded in drawing loads through most difficult places with remarkable ease. The india-rubber wheels, unhappily, did not succeed. The clay was spurted up from under the wheels, and entered between the india-rubber and the iron rim round which the india-rubber was placed, and so lubricated the parts that there was a revolution of the iron rim within the india-rubber. Notwithstanding this failure on wet clay soil he still had a very high opinion of india-rubber tires for road purposes. He was

rather alarmed, however, at the statement made in the Paper that the old india-rubber tires were of very little value. The late Mr. Thomson, the inventor of the india-rubber wheel, used to urge that the tires could be worked up again, and re-used, and that a considerable sum could be allowed for old tires; but, according to the present statements, that was not so. That, as Mr. Bramwell had said, alarmed him, because it made the expense of those tires very great. For instance, Lieutenant Crompton estimated that a set of tires which cost £234 would run only 8,000 miles; thus making the working cost of the india-rubber tires about 7*d.* per mile, and such a cost as that was nearly prohibitory of their use. Allusion was made in the Paper to the contrivance adopted by Messrs. Aveling and Porter between their motive power and the driving wheels, namely, that of Holdsworth's 'jack-in-the-box'—invented to be used in cotton-spinning machinery—whereby the engine could turn round any corner without throwing the wheels out of gear; but there was one difficulty about that, which was, that when one of the wheels got into a hard place, or, rather, into a slippery place, the whole energy of the engine could be devoted to turning the wheel round over that slippery place without any forward movement at all; but he believed Mr. Aveling had lately devised means whereby he was able to throw out the compensating arrangement, and thus to make the wheels for a time as though they were rigidly connected, so that the ill effects Mr. Bramwell had alluded to might not take place.

Mr. G. A. C. Bremme said the past history of the traction engine, as recorded and explained in the Paper, seemed to furnish ample evidence that the want of suitable propellers or driving wheels had been the primary and chief cause of the failures and disappointments hitherto experienced. Instead, however, of occupying time by reviewing the various propellers which had already been before the public, he would, with the permission of the Meeting, state a few facts relating to a class of steel tire wheels not so well known. The pair of wheels mentioned in the Paper as being now under trial at Chatham had been at work, attached to one of the Royal Engineer 6-H.P. steam sappers, since the 15th of January last, and had now run an aggregate distance of 150 miles. They were flexible, and would, therefore, in future, and in accordance with the Author's classification, be called 'flexible steel tire wheels.' The Royal Engineers had not as yet reported on them, but the results of private experiments confirmed Mr. Bremme's opinion that, for the sake of economy and safety, the flexible steel tire wheel would ultimately be

generally and exclusively used for tractive purposes on the common road. The pair of wheels in question weighed 46 cwts., which was about the same as that of a pair of india-rubber wheels of equal size and capability, and their circumference was 206 in. The weight of the pair of rigid wheels belonging to the steam sapper was about 16 cwts., and their circumference was 189 in. From empirical data he found that a pair of steel tire wheels, specially adapted to the 6-H.P. steam sapper used, need not weigh more than 30 cwts. The flexible tires were made of ordinary sheer steel, and were untempered. Their actual deflection when working was not quite one-fourth of that admissible before permanent set began, and the steel tire might therefore be considered indestructible. The weight of steel in each tire was 4 cwts., and its cross-sectional area was 8 square inches. An equivalent india-rubber tire would have necessitated a cross section of at least 60 square inches. It might be assumed that in the construction of elastic tires 80 lbs. of steel was equal in efficiency to 100 lbs. of india-rubber. The wrought-iron tread pieces or shoes were 6 in. broad, perfectly smooth, and close together. The positive and peculiar connection between the tire and the central part in those wheels obviated two material defects peculiar to, and unavoidable in, the india-rubber wheels, namely:—1, loss of power through the slip of the central part; 2, excessive intensity of pressure and consequent friction and wear at some point or other of the wheel. To remedy those defects in india-rubber wheels would seriously affect their qualities of flexibility and elasticity. In working the sapper with the steel tire wheels, the attendant riding on it felt no vibrations. The wheels in hauling a load on paved or macadam roads, although perfectly smooth, did not slip; their adhesion, therefore, was purely frictional, and—not being dependent, as in the case of rigid wheels, on any projections entering and lacerating the face of the road—was always reliable. In an experiment made on the 18th of January last the steel tire wheels took a 5-ton gun up an incline of 1 in 8, near Melville Hospital, Brompton, with 80 lbs. boiler pressure, and a gross load of 11½ tons. The load on the drivers was 85 cwts.; the allowance for gravity and road friction was 34 cwts.; the indicated coefficient of adhesion 0·4, and the actual average coefficient was estimated at 0·5. A pair of rigid wheels of the same weight and circumference would have required 94 lbs. boiler pressure, or 14 lbs. more than that required by the steel tire wheels. This difference was due to the fact that the road friction of the steel tire wheels was considerably less than that of the rigid

driving wheels. As regarded the saving of first cost arising from the use of the steel tire wheel, it might be sufficient to state that the difference of cost between an india-rubber tire and a steel tire was also the difference of cost between the respective wheels. This difference represented a large saving, as, for instance, in the case of the wheels of the 'Ravee,' it amounted to from £180 to £200.

Mr. R. J. Quelch said, he concurred in the idea that horses would soon become so familiar with steam carriages in ordinary use on the public highways as to be driven past them without fright or danger. That such would be the case he inferred from the quiet behaviour of horses at work in and about railway stations, and also from the fact that all animals grazing alongside the lines, though at first scared by the sights and sounds of locomotive traffic, very soon became so accustomed to it as to be oblivious to what was going on around them.

With reference to the use of a canopy over the roof of the steam passenger carriage alluded to by Mr. Grantham, it was evident that unless it was imagined the question of perfect combustion had been satisfactorily solved, or as long as the chimney was placed just above the roof of the carriage, the passengers must necessarily be subject to a continual shower of unburnt carbon and ashes. Mr. Quelch, however, considered that there was not the slightest difficulty in designing a light wrought-iron roof capable of sheltering the passengers from all possible annoyance. It had also been alleged that passengers would never consent to travel in such dangerous proximity to the boiler of the engine, and would be frightened by the slightest escape of steam through the floor of the carriage. Now this objection was utterly meaningless, for passengers on board river steamers could be there observed daily sitting in the closest proximity to the boiler, without apparently noticing either the escape of steam or even betraying the slightest fear while sitting directly over the boiler itself.

Until the Act of Parliament was altered so as to place steam carriages on a similar footing to other vehicles, the question before the Meeting would not be satisfactorily solved. Practical engineers were not likely to spend their valuable time in working out designs which could never be carried into execution; but when the existing absurd restrictions were rescinded, they would be found both willing and able to deal with the mechanical difficulties involved.

Mr. H. Gore thought that those who had recently devoted their attention to this question—as exemplified by the Paper and the

drawings before the Meeting—were endeavouring to follow too closely some form, or modification of form, of the ordinary locomotive engine. That he considered a mistake. He had given much consideration to the mode in which tramways were to be worked, and he had come to the conclusion—more particularly with regard to those abroad—that it was essential for their success that they should be enabled to use to a certain extent locomotive power upon them. It appeared to him that the designers of steam tramway carriages had forgotten an essential point, namely, that they were not dealing with railways. In dealing with tramways which had to pass through populous streets, and to turn round corners on curves of very short radius, with rails that did not admit of super-elevation, engineers were restricted by the grooves of those rails to a very peculiar mode of traction, all or most of which conditions seemed to be lost sight of by the designers of tramway locomotives or tramway steam carriages. He alluded especially to the systems of Mr. Todd and of Mr. Grantham. With regard to the former it was evident, in the case of a curve of 30 ft. radius with an engine and detached carriage, the engine would probably pass round, but the carriage would most certainly slip off the tram, and perhaps run into the centre of the road. He had traveled behind tramway locomotives in America, and he knew from personal experience the results. So long as they ran on long straight lines, or on curves of 150 ft. radius, the steam cars did very well, but with curves of 30 ft. or 40 ft. radius it was a different matter. In Baltimore, with an engine and detached carriage, the latter became placed in the middle of the road on going round a curve. With Mr. Grantham's steam carriage it would be impossible to pass round short curves, owing to the distance between the bearing points of the wheels being so great. There were, on many existing tramways, curves, of 32 ft. and 33 ft. radius laid with grooved rails on both sides. A carriage of the description proposed by Mr. Grantham, would go off the first time it was attempted to pass it round such curves. Knowing the difficulty of getting the ordinary horse car on to the line again, it might be imagined what trouble and delay would attend that operation when it had to be performed with a heavily weighted steam tramway carriage. But there was another great difficulty which had not been taken into consideration. How was a steam car to be guided round such curves? Those connected with tramways knew that on a curve of small radius as a matter of course the horses were drawn off the curve towards its inner part in order to give a tendency to the carriage similar to that produced with a super-elevation of the outer rail; but how could that be done

with any of those arrangements? Hancock's carriage—which Mr. Gore believed engineers must eventually adopt, if they ever attempted to apply steam to tramway locomotion—could go round such curves. He had traveled by it round the sharp curve at the 'Angel' at Islington, and another at London Wall, and it went round both with great facility. It was most important that inventors or designers of steam tramway carriages should adapt them as closely as possible to some existing form of carriage; and in his opinion the engine and carriage should be self-contained. Trials in the United States pointed in that direction; and he believed that, out of the many experiments that had been made, the only carriage which was feasible was that designed by Messrs. Gray and Hunt, of Baltimore; and that was, to all intents, a modification of the arrangements of Hancock's steam carriage applied to tramway purposes.[1]

Mr. David Greig said, the subject might be divided into three heads:—1, the effect of legislative enactments; 2, the adhesion of the wheels; 3, the capacity and durability of the roads in reference to a heavier and more wearing character of traffic. At present the state of legislation was such as to keep inventive minds from studying the question of steam locomotion on common roads. No man with capital was inclined to embark in an undertaking that was liable to be stopped at the caprice of any nervous individual. If the legislative enactments were satisfactory the arrangements might be safely left to the engineers; and therefore he did not propose to enter very fully into that branch of the subject. The mechanical arrangements should not be too ingenious. If an engine was constructed as lightly as had been proposed, it would be likely to go to pieces even if made of the best steel. His experience had convinced him that the fewer parts that were put into a traction engine the better.

Adhesion was a matter obviously intimately connected with the structure of the wheel. No wheel would take a load with the same resistance as one with an india-rubber tire, or occasion so small an amount of destruction of the road. Although he had expended much time and money in perfecting this class of wheels, he was still sanguine as to their ultimate success. At present the trials had shown that they were the most efficient, and that the locomotives mounted upon them could traverse ground inaccessible to others. But, on the other hand, the cost, especially as regards repairs, was so great

[1] *Vide* also "Propulsion of Carriages on Common Roads by power other than animal power." 8vo. London, 1873.—H.G.

as to impede their more general adoption. The results of the trials at Wolverhampton did not give a fair idea of the capabilities of the india-rubber tire, as it slid round like a locomotive on greasy rails, whereas it should have been held securely as in a rigid wheel. The power was not, therefore, applied upon the periphery of the wheel.

The capacity and durability of the roads was limited to the weight and adhesion which they would stand. It was not a matter of the power which the crank shaft would give, but of the adhesion of the periphery of the wheel, and that was limited. The result of his experience had tended to prove that small engines with light loads, driven at a moderate speed, were most available. He did not approve of the use of high speed road locomotives, as he believed that their use would endanger the other traffic. With high speed, the steering would be difficult and a collision might occur, and any inequality in the road would occasion a sudden, perhaps dangerous, shock to the engine. On a tramway, a speed might be allowed which could not be allowed on an ordinary road, where a stone only $\frac{1}{2}$ in. thick would occasion a sensible jar to a carriage traveling at a high velocity.

Mr. J. Grantham said, the steam engines used on common roads were generally called 'road engines,' in contradistinction to those on tramways, which were styled 'tramway engines.' Having watched for thirty years the progress of road engines, he had come to the conclusion that past experience indicated failure rather than success. No doubt there were circumstances where the common road engine might be useful; as, for instance, for military and agricultural purposes; because the same engine which worked machinery could be used for transporting the carriage itself. But he felt that nothing had hitherto transpired to warrant their adoption for ordinary purposes of traffic, for passengers and the conveyance of goods. A hard and uniform surface was an essential element in the use of the road steam engine. Tramways were being introduced rapidly, and might be employed to a much greater extent if steam could be applied in the place of horses. The use of steam engines would afford an opportunity for the introduction of tramways into small towns and other places where the traffic was not sufficient to warrant the construction and working of railways at a large cost. He considered there were three essentials in the construction of steam tramway carriages, namely:—1, they should have a short wheel base; 2, they should be so constructed as to be capable of being driven from either end, and of being worked both ways —backward and forward—without being turned; 3, there should

be a clear passage for passengers from one end of the carriage to the other.

The other question, of whether steam tramway carriages would make such a noise as to preclude their use in crowded towns, he was happy to say was on the verge of being tested in a full-sized carriage built for that purpose. In a long carriage a short and narrow wheel base was essential to turning round sharp curves. A bogie frame with four wheels formed even a better angle with regard to the rails than the short wheel base of the present tramways. As it was necessary that, under any circumstances, the wheel base should be short, it was equally essential that the weight should be disposed as much as possible in the centre of the carriage. With regard to passengers inside a steam carriage, experiment had shown that they would be as comfortable as with horse traction, and perhaps more so. It had also been ascertained that the starting and stopping of a steam tramway carriage was more easily effected, and the vehicle was under better control than with horses. He was not prepared to give an opinion as to how far the anticipated annoyance in the streets from the chimney would be overcome. Various means had been suggested with a view to protect the outside passengers from being powdered with dust from the chimney. He had been recommended to put the chimney at the end of the carriage, and to turn it in different directions. It had been suggested also that a traction engine drawing an ordinary passenger car would cause less annoyance; but he considered that by such arrangements the passengers would be more exposed to the smoke and dust. If the chimney was in the centre of the carriage, in nine cases out of ten the dust would fly clear ; at any rate its annoyance would be small. An opinion had been expressed, to the effect that there was danger in having the boiler in the middle of the carriage, and something had been said about its bursting. It was well known that tubes used in boilers, like that proposed by him, when they burst, would not blow up the carriage and the people in it. They only made a spluttering noise and put out the fires. He had witnessed such an occurrence in the carriage he had referred to. A joint in the steam pipe, being badly made, burst; but it caused no inconvenience to the people inside the carriage; in fact, no one but the engineer was aware of it. No doubt the objections and difficulties urged against the use of steam passenger tramway carriages would eventually be surmounted, like those opposed to the introduction of locomotives on railways.

Mr. R. C. Ransome said, he saw, four years, or five years ago, in Baltimore, a steam tramway carriage at work, between the city and

the People's Park, a distance of 4 miles or 5 miles. The form of the carriage was similar to that of an ordinary London omnibus or tramway car, with an engine at the end; and it appeared to answer well. The starting and stopping was done with great facility, and the motion was easy; the heat was not unpleasant, and there was none of the dust mentioned by previous speakers. The thorough mechanical practicability of that plan of steam traction for tramway purposes might, therefore, be considered as established; and, so far as the engineering or mechanical part of the subject was concerned, the steam tramway cars might at once be run in London without the necessity for designing fresh rolling-stock. But it was a very different thing to run from Baltimore to the Park to what it would be to run in narrow thoroughfares, crowded as those of London, where the difficulties spoken of must exist. He ventured to say the Legislature would never give its sanction that steam tramway carriages should run in crowded and narrow streets mixed up with the general traffic; and he was sure popular opinion would be against it. If it was desired to convey business men to and from the suburbs by steam carriages, at a rate of 10 miles per hour, it would be much more practicable to do so by bridging over the present streets with a series of columns and girders—which would carry the rails and the traffic above the heads of persons in the street, without much obstruction of light and air—than to attempt to do it by tramways on the level of the ground. For the hauling of heavy loads, the engines for steam ploughing made by Mr. Fowler, Messrs. Aveling, and other manufacturers were very perfect and useful. But for the general carrying purposes of a farm—such for instance as carrying crops, manure, &c., or for thrashing grain—an engine especially adapted and strong enough for ploughing and cultivating could not be employed to advantage. The engine which contained power enough to break up land would be too heavy for the purpose of conveying produce off the land, and for the other uses for which it would be required in an old country like England. But in a new country, such as the American prairies, and the steppes of Russia, and in India, something forcible might be said on the opposite side of the question; although in such countries the difficulties of providing the skilled workmen required for the repairing shops, together with a regular supply of coals and water, would have to be taken into consideration. As far as England was concerned, he thought there was no room for a medium between the systems of traction already adopted, namely, by horses on common roads and by locomotives on railroads. He considered that in places where steam traction on common roads

was admissible, the maximum of success had been obtained; indeed, it might be asserted that very little progress had been made in the conveyance of passengers by steam at high speeds on common roads since the time when Hancock's steam carriage was introduced.

Mr. E. A. Cowper said, the earliest locomotive steam engine for common roads, he believed, had been made in 1769, by a Frenchman of the name of Nicholas Joseph Cugnot, who was born at Void, in Lorraine, on the 26th of July, 1729, and died at Paris in 1804. Mr. Cowper had seen the model in the Conservatoire des Arts et Métiers in Paris, and afterwards the engine itself, laid up in a repository for old machines in connection with the Conservatoire.[1] The machine traveled on three wheels, one in front and two behind, and was furnished with steering tackle to the front wheel. It was composed of two parts, the fore part being supported by a single driving wheel. They were united by a pin and a toothed sector, fixed on the framing of the front part; the hind part was merely a carriage on two wheels, intended to convey the load, and was furnished in front with a seat for the conductor. The fore part carried a copper boiler, having a furnace inside, with two small chimneys, and two single-acting brass steam cylinders, which were provided with four-way cocks, communicating with the boiler by a pipe and with machinery for communicating the motion of the pistons to the driving wheel. The conductor could turn the carriage at an angle of from 15° to 20°, by means of a set of cog-wheels, the last of which worked on a toothed sector, and the first of which was turned by a spindle furnished at the top with a double handle in front of the seat. Running upon three wheels only, with the weight of the boiler and engine overhanging in front, it was by no means a steady machine, and in passing along a street in Paris, near where the church of the Madelaine now stands, it overbalanced itself while turning a corner, and the inventor was forthwith locked up in prison, and the machine as well. A number of trials were, however, made in the presence of the Duc de Choiseul, then Minister of War, General Gribeauval, First Inspector-General of Artillery, and other eminent persons; but it was found that the engine could not travel faster than $2\frac{1}{4}$ miles per hour when carrying 4 persons, and the boiler not being large enough, it could not keep going longer than 12 minutes or 15 minutes at a time. Those trials were made fifteen years before the engine of Murdock was brought forward; and, so

[1] *Vide* also "Institution of Mechanical Engineers. Proceedings, 1853." Birmingham. Page 33.

far as Mr. Cowper knew, Cugnot's engine was the first locomotive ever made.

After Cugnot there were several persons whose names should be mentioned as having suggested the use of steam for locomotion, namely:—Watt, in 1784; Oliver Evans, in 1786; Professor Robinson, in 1795; and lastly, Trevithick and Vivian, in 1804, who not only ran a locomotive steam-engine, but laid down rails for it to run on, at Merthyr Tydvil, in South Wales; and from that time the improvements introduced in locomotives and railways had been almost incessant.

Mr. Henry Chapman said, the Author had omitted to mention in his Paper the last improvement which had been made in applying steam to traction on common roads; and Mr. Chapman was the more surprised at the oversight, as the system was being applied on a large scale, in a populous town, with steep gradients, and severe curves, by the Lisbon Steam Tramway Company (Limited). One of the engines was tried a short time time ago on an experimental line near London and gave complete satisfaction. The system was invented by Mr. Larmanjat, and consisted of a single rail laid in the middle of the track; the driving wheels of the engine, bearing nearly the whole weight, ran upon the ordinary road, the guiding wheels only running on the rail. The wagons and carriages had 4 wheels, of which 2 bore on the rail and the other 2—carrying just weight enough on them to steady the vehicle—on the road. The distribution of the weight of the vehicles was thus made in the reverse way to that of the locomotives; thereby obtaining an increased adhesion for the driving wheels of the locomotive, and a reduction of resistance in the traction of the wagons and carriages. The use of one rail almost entirely obviated the difficulty of going round curves.

The engines, made by Messrs. Sharp, Stewart, and Co. for the Lisbon Tramway Company, were from the designs of Mr. Trevithick. They weighed $13\frac{1}{2}$ tons, and had smooth wrought-iron tires to the driving wheels; but Mr. Chapman had seen one last year running on an experimental line in Paris, weighing only $5\frac{1}{2}$ tons. It had Thomson's india-rubber tires, and was one of a number to be used on a canal in Burgundy, where Mr. Larmanjat had the concession for the haulage. Mr. Chapman thought the system was especially applicable in such cases, where the banks were not sufficiently secure to allow of a heavy traction engine on the towing-path. The central rail had the further advantage of preventing the engine sliding into the canal, to which there was always a tendency in consequence of the angle at which the boats were drawn.

As to the effect on horses of steam engines on high roads, he thought the danger had been much exaggerated. Of course no one anticipated steam engines being used in Fleet Street or Cheapside; but at Nantes, a town intersected by canals, the railway ran along one side of the canal, on a level with the principal streets, and only divided from it by a small low fence, and he had never seen a horse frightened, although there were trains constantly running, and no warning of their approach, except the ordinary screech signal with the whistle. The experiments with Thomson's engine, in one of the crowded and fashionable parts of Paris, had been similarly successful.

Mr. Francis Trevithick, through the Secretary, stated, that Mr. Richard Trevithick designed his high-pressure steam locomotive in 1796, and during the following three years, or four years, constructed as many working models, one of which was in the Kensington Patent Museum. In 1800, his full-size locomotive was being constructed at Hayle, and made its first memorable trial on Christmas Eve, 1801. The following report appeared in the newspapers of the day:—"A carriage has been constructed containing a small steam engine, the force of which was found sufficient, upon trial, to impel the carriage, containing several persons, amounting at least to a ton and a half weight, against a hill of considerable steepness, at the rate of four miles an hour. Upon a level road it ran at the rate of eight or nine miles an hour."

In 1802 Trevithick fully described his inventions in his patent, and constructed an improved locomotive, which made several runs on common roads at Camborne. In 1803, another locomotive constructed by him, with larger driving wheels, ran for many days in the streets of London, attaining a speed of 8 miles or 9 miles per hour. In 1804, he completed a tramway locomotive at Penydarran, of which he wrote:—"We carried ten tons of iron, five wagons, and seventy men, the whole journey, above nine miles." In 1805, he took an improved tramway locomotive to the Wylam colliery, and explained its construction to George Stephenson, then employed on those works. A notice of it, dated 1805, might be seen at the Kensington Patent Museum, which stated:—"I saw an engine this day upon a new plan: it is to draw three wagons of coal, each weighing about $3\frac{1}{2}$ tons, at an expected speed of four miles per hour."

In 1808 Trevithick constructed a railway in London, and in describing it wrote as follows:—"About four or five days ago I tried the engine, which worked exceedingly well; but the ground was very soft, and the engine (about 8 tons) sank the timbers under the rails, and broke a great number of them. I have now taken

up the whole of the timber and iron, and have laid balks of from 12 to 14 inches square on the ground." A well-known Engineer, Mr. Hawkins, in reference to this engine also wrote :—"I rode on it, with my watch in hand, at the rate of twelve miles an hour. The engine was exhibited at one shilling admittance, including a ride; it ran for some weeks." It was, therefore, evident that Trevithick, after ten years, or twelve years of herculean single-handed labour, was the man who first conveyed the public by steam for hire.[1]

Mr. W. F. Batho, through the Secretary, said, the first self-propelling roller made in England was designed by him, in 1863, for the municipality of Calcutta, at the suggestion of their Engineer, Mr. W. Clark. About seventy rollers of that type were constructed, under licences from the inventors, by Messrs. Aveling and Porter during the last four years, or five years. The date of the patent of the French roller was nearly a year later than that of Messrs. Clark and Batho. The French Engineers had, however, demonstrated the advantage and economy of rolling by steam power, even with an inferior machine. Mr. Batho had found it a hopeless task to endeavour to get the road authorities in England to take up the subject before the French had proved its utility and efficiency. So strong was previously the prejudice against it, that an eminent English road contractor had told him that the machine should be called a 'road destroyer,' and not a 'road roller.'

A new type of roller had been proposed for use in narrow and crooked places and for new road making. It might be necessary to have a narrower machine than had hitherto been made, but the arrangement of a pair of conical wheels carried by a vertical spindle, with the bearing at a distance from the resistance, appeared to be most unmechanical; and could hardly be considered an improvement on the turntable arrangement hitherto in use. The conical wheels would both grind the metal and themselves, on account of the varying speeds traveled by the different parts of the cones; and the undue strain thrown on the boiler by the leverage of the vertical spindle was very objectionable.

He found that from $2\frac{1}{2}$ tons to 3 tons per foot width of roller was the weight best suited to make a good road, and that a machine 9 ft. wide was the most economical. With it the same labour only was required as for driving a narrower machine and less water and fuel in proportion; besides, it had the advantage of being able to

[1] *Vide* also "Life of Richard Trevithick, with an Account of his Inventions." London, 1872.

accomplish a larger area in a shorter time. With this class of roller an average of 3,000 square yards per day could be rolled.

Mr. HEAD, in reply, said, he considered that it would be some time before tramway engines would come into use in towns; but there could be no doubt as to their applicability to suburbs and outskirts. It must be borne in mind that the tramway companies had a large stock of cars now running, and they would not be in a position to use new cars with enclosed engines, however much such a combination might come into use at some future period. As regarded the wheel base, it was desirable that it should be narrow for engines which ran in towns. In the outskirts the roads were wider, and the curves might be of greater radius; and under those conditions there would be no difficulty in making an engine capable of passing round any moderate curve.

With respect to the employment of traction engines and road locomotives for agricultural purposes, he did not agree with Mr. Ransome, that the number employed must be limited, but Mr. Head thought the demand for such machines would largely increase in proportion as the price of labour augmented. It would probably be found that farmers would use light engines. Engineers should therefore devote their attention to making the machinery as light as possible, so that engines could be used both for hauling and tilling. The best form of wheel for such a use was Aveling's, or Fowler's, wrought-iron wheel, with wrought-iron bands fitted with holes for spuds. Sufficient adhesion was thus afforded for ordinary roads. The only difficulty of using the locomotive on some farm roads was on account of their narrowness, and the rough and sandy nature of their surface.

Crops would most likely be generally harvested by the use of wire ropes on the plan adopted by Mr. David Greig; namely, the crop would be collected in the field, and placed upon wagons which would be hauled to the headland by a wire rope attached to a fixed engine placed on the headland, and from thence transported by a light traction engine to the homestead or to the place where the crops would be stacked.

With respect to the tramway engine for the Lisbon and Cintra line, mentioned by Mr. Chapman, Mr. Head believed it was designed that the driving wheels should run on a tramway made of wood. He did not think it possible to make an engine which would run with one set of wheels on a single rail in the middle of the tram, while the driving wheels were running on an irregular surface like a common road.

In pursuance of the notice on the card of the Meetings, it was proposed, and resolved unanimously :—

> "That in order to insure a fuller attendance of Members than could be obtained on Easter Tuesday, the Meeting be adjourned until Tuesday evening, the 22nd of April."

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April 22, 1873.

T. HAWKSLEY, President,

in the Chair.

The discussion upon the Paper, No. 1,370, "On the Rise and Progress of Steam Locomotion on Common Roads," by Mr. J. Head was continued throughout the evening to the exclusion of any other subject.

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April 29, 1873.

T. HAWKSLEY, President,
in the Chair.

No. 1,353.—"The Rigi Railway." By WILLIAM POLE, F.R.S., M. Inst. C.E.[1]

THE Council have lately made a suggestion, that Members traveling abroad would do well to communicate to the Institution information as to any remarkable engineering works they may meet with in foreign countries. The Author in this Paper presents a few notes descriptive of the peculiar features of a railway of an unusual character, which he had the opportunity of examining on a late journey to Switzerland.

The Swiss have the habit of doing masterly engineering work without ostentation. Members of the profession who visit their country are continually meeting with examples of engineering boldness and skill of which they have never before heard, and which they always find applied to thoroughly practical ends.

Perhaps the best known Swiss engineering works are the magnificent Alpine roads; but there are many less obtrusive constructions which do no less credit to their originators. The wire bridge at Freiberg, for example, although a cobweb in appearance, has furnished for many years a most useful carriage-way over a chasm 1,000 ft. wide and nearly 200 ft. deep, and is a structure of which the Swiss nation may be proud. The bold and ingenious treatment throughout the country of the often almost unmanageble mountain water systems, and their enforced subservience to the industrial and the commercial interests of the localities, would afford of itself an attractive study to the engineer.

The mechanical talents of the Swiss are well known, and manufacturing industry, calling largely into aid the skill of the engineer, occupies no mean proportion of the inhabitants. In some branches, such as watches and certain textile fabrics, they have no rivals in

[1] For much of the detailed information contained in this Paper, and for the illustrative drawings, the Author is indebted to a work entitled "Die Rigi-Eisenbahn, mit Zahnradbetrieb. Beschrieben von J. H. Kronauer, Professor," Winterthur, 1871.

the world; and in heavier manufactures, such as locomotives, machinery, and steam-boats, they are able to enter into a not unworthy competition with our own country.

As might be expected, the Swiss have not been slow to avail themselves of the benefits of railway communication. Their railway system is admirably laid out, furnishing extended accommodation with very moderate outlay; they never shrink from difficulty or expense where necessary, and many of their lines are of a very bold character; while on the other hand they have economized the construction as much as is consistent with efficiency. They have kept clear of many of the 'quasi' economical delusions, which, somewhat to the discredit of our mechanical knowledge, are too fashionable in the present day; but, on the other hand, they have not wasted money in ostentation, in competition, in preliminary expenses, or in unnecessary outlay of any kind. The management is sensible, the trains are sufficient to give ample accommodation, the speed is moderate, the fares are reasonable, and, as a consequence of all this, the railways are not only a great boon to the country, but they pay.

It is also worthy of remark that the Swiss were the first to entertain seriously the project of railway communication across the Alps, a well devised scheme for the purpose—that of the Lukmanier Pass—having been projected, many years ago, in conjunction with an English engineer, Mr. G. W. Hemans, Vice-President Inst. C.E.; and although this was not carried out, yet a railway across another part of the Alps—the Tyrolese Pass of the Brenner, between Munich and Verona—practicable for ordinary locomotives, and with no long tunnel—was quietly constructed and set to work before anything was publicly known of it in this country.[1]

In the ordinary railway system of Switzerland the engineers have adhered to established models, but a railway—that on the Rigi near Lucerne—has been lately made which, from its peculiar conditions, has required a construction quite novel.

The Rigi is an isolated mountain, standing close to the north side of the Lake of the Four Cantons. Its summit is about 4,500 ft. above the lake, and nearly 6,000 ft. above the sea, and from its peculiar position it commands probably the most magnificent panoramic view in the world. To the north the spectator looks down on the whole of the great plain of North Switzerland, beautifully diversified with lakes, hills, woods, towns, and rivers, the prospect extending over the distant Jura to France and Germany.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxvi., p. 312.

To the south the view is of a totally different character, consisting of the most picturesque masses of colossal rocks and mountains, capped with a semicircle of glaciers and eternal snows. No wonder, therefore, that as the mountain is easily accessible and within a few miles of one of the most frequented Swiss towns, it should attract a large number of visitors during the summer season. A few years ago the average number of visitors was estimated at 40,000 annually, but the number is now greater than this, and it is increasing every year.

Hitherto the only way of ascending the Rigi has been on foot or on horseback, good bridle roads having been formed by 'zigzags' up the steep slopes from Gersau and Weggis on the south, from Küssnacht on the west, and from Arth on the north. The ascent on horses from either of these places occupies about 3 hours, or 3½ hours, and costs about 12 francs. No carriage road up the mountain has been designed. With a practicable gradient, such a road must be very long, and more costly than the object would warrant, particularly as the shorter bridle roads would, in any case, continue to be largely used.

Some years ago it occurred to a Swiss engineer, M. Riggenbach, manager of the railway workshops at Olten, that it might be possible to construct up the mountain a steep railway of short length and moderate cost, on which passengers might be conveyed by special means. The south flank of the mountain was surveyed with this view, and it was found to admit of the easy construction of a line from Vitznau, on the Lake of Lucerne, to a point at the division of the Cantons of Lucerne and Schwytz, and within about a mile of the summit. This line was 3⅓ miles long, and the total rise was 3,930 ft.; the maximum gradient, which extended over about one-third of the whole length, being 1 in 4.

Of course the most important question to consider was, whether efficient and safe means could be devised for working a railway of this unusual steepness. The ordinary locomotive, acting by the adhesion of the wheels, was out of the question; and as there were great objections to fixed engines and ropes, M. Riggenbach bethought him of the old plan of the 'rack and pinion,' which was invented and used in the infancy of railways; it having been patented by Mr. Blenkinsop in 1811, and actually constructed by him at Middleton collieries, near Leeds, in the following year.[1]

M. Riggenbach believed that when constructed and furnished

[1] According to Mr. Smiles, this railway was the first instance of the regular employment of locomotive power for commercial purposes. It worked for some years, and was one of the principal curiosities of the district.

with modern appliances this system would offer peculiar advantages for steep mountain railways. In 1863, he had patented in France an application of the system for this purpose, and a model of it had attracted much attention, but for some years no opportunity had offered for carrying it into practice.

In 1868, however, it was ascertained that a very steep railway had been constructed in America on the same principle, and after the confirmation of this by inquiry, M. Riggenbach and two other Swiss engineers, Messrs. Näff and Zschokke, associated themselves together with the view of laying down a line of the kind on the Rigi.

Application was at once made to the authorities, and in the early part of 1869, the Lucerne government granted a concession for the construction and working of the proposed railway. A company was formed with a capital of £50,000; the shares were quickly taken up, and the works were commenced in November of the same year. They involved no great difficulties, and were prosecuted with such vigour, that the line would have been opened in the autumn of the following year, but the delivery of the last instalments of the rails, which had been ordered from France, was stopped by the war, and in consequence the opening was delayed until the 21st May, 1871. Since that time it has been working with great success, and has carried a very large number of passengers without any mishap or difficulty of any kind. It is now being extended, under a new concession from the canton of Schwytz, to the summit of the mountain, and the whole will be at work in the summer of 1873.

The gradient over one-third of the whole line is, as already stated, 1 in 4; the gradients in the other parts vary between that gradient and 1 in 6, except in some few places, where the line is made purposely much flatter. At the stations, for example, it is nearly level, but not quite, for a reason that will be given hereafter. Also at a short distance above each stopping place the Engineers have taken the precaution of laying a short piece nearly horizontal, with a view of giving the opportunity of checking the speed, if necessary, before coming to the station. The curves have a radius of 180 mètres, or 8½ chains.

The works of formation are much lighter and simpler than might be expected for a railway of this character. The line is formed almost entirely by benching on the sloping side of the rock, with occasional revêtement walls on the outside. The rock is the well-known Nägelflue or pudding-stone, a conglomerate somewhat hard in texture, but which appears to be worked without

great difficulty or expense. There is one rather large cutting, and one tunnel 250 ft. long. There is one light wrought-iron girder bridge of three spans over a ravine, the total length being about 250 ft., and the height above the stream 75 ft. Beyond these there are no works worth mentioning. The station buildings are of wood—as is very common in Switzerland—and of cheap and simple construction; and there is a small workshop established at Vitznau for the mechanical necessities of the line.

The permanent way has been designed and constructed with much care, as the addition of the rack has rendered necessary great precision and stability in this part of the work. It is shown in Figs. 1, 2, 3, and 4 (Plate 18), and it consists of cross sleepers united firmly into a strong frame by longitudinal timbers on each side. The cross sleepers are 7 in. broad by 6 in. deep, and 8 ft. long; they are laid 2 ft. 6 in. apart from centre to centre. The longitudinal timbers are of the same scantling and are laid on the top of the cross sleepers at a distance of 6 ft. 6 in. apart from centre to centre. They are notched upon the cross sleepers, and are bolted down to each by strong wood screws. By this construction a strong and stiff timber framing is formed, which is imbedded in ballast and packed in the usual way: the stiffness is necessary, because the slight settlements and irregularities of individual sleepers, which are harmless enough on ordinary railways, are inadmissible on the Rigi railway on account of the rack, the position of which must be maintained with the utmost possible accuracy. As a security against any possible slipping of the framing, it is strongly secured, at intervals of 300 ft., or 400 ft., to masonry foundations built into the formation below.

The gauge is the usual one of 4 ft. $8\frac{1}{2}$ in., for, although this is in every respect a special and exceptional line, and intended for the very lightest character of traffic, the Swiss, with their usual good practical sense, have avoided the foolish fallacy of narrowing the gauge. They have seen—what the Author thinks should be obvious enough to every intelligent engineer—that lightness and cheapness of structure could be obtained without the disadvantageous and unmechanical alteration of bringing the wheels under the carriages closer together; and hence, although there is very little likelihood of the Rigi railway ever working in conjunction with any other, they have retained, very wisely, the accustomed width between the rails.

The rails are of the Vignoles shape, and weigh $16\frac{2}{3}$ kilogrammes per metre, or 34 lbs. per yard. They are spiked down to the cross sleepers, and the joints are fished in the usual way.

In the middle of the line, between the rails, is laid the rack bar (Figs. 3 and 4). As this is perhaps the most important portion of the line, great pains have been taken with its construction. It is made entirely of wrought iron—cast iron would of course have been cheaper, but the danger of fracture put the use of this material out of the question. It is formed by two wrought-iron flanched longitudinal cheek bars, the wrought-iron teeth being placed between them and fixed by riveting on each side. It is thus stiff and strong, and is probably as cheap a construction as could be devised in wrought iron. The height of the cheek bars is $4\frac{3}{4}$ in.

The pitch or distance apart of the teeth from centre to centre is 10 centimètres or nearly 4 in., they are 5 in. long, in the clear between the cheeks, 1·5 in. high, 2·2 in. wide at the bottom, and 1·3 in. at the top. They have been cut from wrought-iron bars, rolled to the exact section required.

The rack is made in lengths of 10 ft. each, which are connected together by fish plates on the lower flanches. It is screwed down to every cross sleeper with wood screws. It will be noticed in Fig. 3 that the joint of the bars is not made half way between the teeth, but that an increased length of the cheek plate is allowed below the lowest tooth of the upper bar. This is in order to meet the danger of this tooth being torn out of the side plates by the downward strain, which would be more likely to occur if the joint were in the middle. Careful experiments were made to determine this part of the construction, and it was found that its resisting power was 43 tons, which—as the maximum force coming on it was only about 5 tons—was believed to give ample security.

The principal difficulty attending the construction of the rack bar was in its adaptation to the curved parts of the line; the cheek bars had to be carefully bent to the exact curvature, and the teeth were inserted so as accurately to converge to the centre of the curve.

The expansion and contraction of the rack bar are provided for by slotted bolt holes and small interstices between the joints.

To shift vehicles from one line on to another, a special contrivance is necessary, the ordinary switches being rendered inapplicable by the rack and pinion. This apparatus will be sufficiently understood from Figs. 5 and 6. It is essentially a segment of a turn-table. The vehicle is made to stand on a portion of the permanent way, which is moveable, bodily, round a centre at its

hinder end; the forward end is then brought opposite the adjoining rail, and the carriage is passed thereon, after which the apparatus is returned to its original position.

The locomotive employed on this railway has naturally many specialities of design, and differs materially from the ordinary type. It has been necessary to abandon the horizontal form of boiler, on account of the effect of the steep gradient on the water-level; hence the boiler has been made vertical, with vertical tubes, and covered with a dome, from the centre of which rises the chimney. The steam pressure is 10 atmospheres; the fuel burnt is coal, and the draft is obtained by the blast of the discharged steam in the usual way.

The axis of the boiler is not placed perpendicularly to the base line of the engine, but is inclined to the perpendicular at an angle of about 1 in 5. The effect of this is to cause the boiler to be upright, or nearly so, when it is running on the line. When it is standing at the stations it leans much out of the vertical; this has a very odd appearance, and is more noticed by the public than any other feature of the railway. It is further a consequence of this arrangement that the locomotive must not be turned, but must always have the same end highest whether it be running up or down.

Fig. 7 will give a general idea of the form and chief peculiarities of the engine. It was designed specially by M. Riggenbach, and built by him in his workshops at Olten. It has a small water tank and coal store at the lower end, where the fireman and stoker stand, and at the upper end is a light iron-framed basket to carry luggage and parcels, as there is no van.

The two cylinders have a diameter of $10\frac{3}{4}$ in. and a stroke of 16 in.; and they are provided with valves, eccentrics, link motion, &c., of the usual kind. They do not act on the driving axle, as the motion of the latter is required to be slow and powerful; the connecting rods, therefore, turn a special crank shaft, which is placed above the driving axle, and is connected to it by spur gearing. The small wheel is 8·7 in. diameter, and the large one is 26 in. diameter, thus giving about 3 revolutions of the engine for one of the driving or cog-wheel shaft.

These spur wheels are strongly made in forged cast steel, and, as a measure of security, they are in duplicate, one pair on each side (Figs. 8 and 12). If one pair should be damaged, the other is considered strong enough to finish the journey.

The wheels carrying the locomotive are 25 in. diameter.

They are not keyed on to the driving shaft, as is customary on railways generally, but they run loose like ordinary road carriage wheels—being kept on by nuts on the outside. This looseness is necessary, because the motion of the axle is determined by the cogged driving wheel, and must be independent of that of the bearing wheels; it is, moreover, a considerable advantage in turning the curves.

The driving cogged wheel is keyed firmly on the middle of the axle. It is about 25 in. diameter at the pitch line, and has 20 teeth; the breadth of the teeth is somewhat less than that of the rack, so as to leave a reasonable clearance on each side (Fig. 9). The wheel is made of the best cast steel, and the teeth have been cut out of the solid, and shaped with great precision.

It will now be clear how the locomotion is produced: the engine shaft, running at a pretty quick speed, drives, by the spur gear, the main axle below, and the cogged wheel, taking fast hold on the teeth of the fixed rack, forces the whole machine to mount the incline.

There is only one class of passengers. Two sizes of passenger carriages are used. The larger carriage is shown in Figs. 10 and 11. It is 28 ft. 6 in. long, and 10 ft. wide, and it is very light. It is covered at the top, but open at the sides, and has movable folding-screens to protect the passengers, when necessary, from the rain. There are 9 light benches, accommodating 6 persons each, or 54 persons in all, and the seats are curved, so as to allow of comfortable sitting whatever inclination the carriage may take on the incline. The smaller carriage holds only 30 passengers. The engine will take up one large carriage or two small ones, fully laden.

It is now desirable to say something of the various precautions which are adopted to secure safety; for it will occur to every one, and especially to engineers, who are well acquainted with railway dangers, that a line of this character must be peculiarly exposed to perils of various kinds, and that unless the precautions taken to guard against these perils are ample and trustworthy, such a line in such a situation could not possess the confidence of the public, and, indeed, ought not to be allowed to work at all. Hence the nature of these precautions must attract the first attention of any scientific visitor, and their description must naturally form one of the most prominent features of an account of the railway.

In the first place, the greatest element of danger existing on ordinary railways, namely, high speed, is here absent, the speed, both of ascent and descent, being limited to between 3 miles and 4 miles per hour. At this velocity collisions become next to im-

possible, seeing that—by means to be hereafter described—the train can be brought to a stand almost instantaneously; and even if a collision did occur, at such a speed no great harm could ensue. Moreover, at this speed all the numerous causes of damage, both to permanent way and to rolling-stock, which result from velocity of motion, entirely disappear.

The dangers to which this line is liable may be comprehended under four heads, namely:—

1. Derailment.
2. Running down the steep incline.
3. Fracture of some part of the machinery.
4. Derangement of some part of the permanent way.

1. It would be a serious thing for an engine or carriage to leave the rails; as, the line being formed on a steep mountain flank, precipices of great depth often occur close alongside the track. The slow speed doubtless contributes to security, yet the rack and pinion apparatus might, under certain accidents, render derailments more likely to occur than on ordinary railways. For example, if a hard substance got between the teeth of the rack, the action of the driving pinion upon it would have a tendency to lift up the engine, when a slipping off sideways would most probably follow.

To meet this liability the following arrangement has been adopted:—At each end of the locomotive are firmly fixed a pair of strong angular jaws (Fig. 4), which embrace the upper flanches on each side of the central or rack rail, leaving about $\frac{5}{8}$ in. play. In the event of the wheels being lifted off the rails, these jaws would catch against the flanches and hold the vehicle in its place. Similar jaws are fixed on every carriage, so that the accident of derailment is rendered impossible, unless by a force great enough to break the jaws, which could hardly by any chance come into action.

2. The danger to be guarded against, of the train running down the incline by its own gravity, is much more formidable. The gradient, of 1 unit rise to 4 units horizontal measurement, makes every ton weight tend to run down with a force of about 544 lbs., and as an ordinary train weighs about 20 tons, there is a force of nearly 11,000 lbs. constantly acting to drive it down the slope. This tendency must of course be resisted in an absolutely trustworthy manner, and independently of all contingency, or the railway could not be usable. And it must be borne in mind that the ordinary means of controlling the downward

impulse on railway inclines, namely, by brakes acting on the wheels of the vehicle, is useless here, on account of the steepness of the inclination. There is much uncertainty as to the coefficient of friction of iron on iron, as so much depends on the state of the surfaces; but it may be fairly assumed that on a gradient of 1 in 4, if the whole of the wheels were locked—which is the maximum effect that the ordinary brakes can produce—the iron would be liable to slide on the iron, and the train would still be in danger of running down.

Hence it has been necessary to devise an entirely different system of control, and this has been accomplished with perfect success. The engine, being the most important vehicle, is provided with no less than three independent means of checking and governing its motion, either of which is capable, if necessary, of entirely stopping it, and holding it in position at pleasure. These consist of a special kind of brake on each of the axles, and an independent control through the medium of the engine.

The axle brakes are not dependent, like ordinary railway brakes, on the friction of the wheel tires on the rails; they are applied in quite a different manner. They act by means of the cog wheel engaging in the rack. When put fully in action they hold the axle of the cog wheel firmly, and prevent it from turning; and the engagement of the cogs in the rack stops the motion and keeps the vehicle securely in its place.

The mode of application of the brake to the driving axle will be seen by reference to Fig. 12. On the middle of the crank axle of the engine is a drum, $x$, about 12 in. diameter, which is encircled by a pair of clip brakes, worked by a screw and handle accessible to the driver, in the usual way. When these are screwed up they pinch the drum firmly, and prevent the shaft from turning, and by means of the spur gear, the cog wheel axle and the cog wheel itself are also held tight, and a hold is obtained on the rack as above described.

But it is not sufficient to trust to this brake alone, as the machinery to which it is attached might meet with some accident, or perhaps from some other cause it might become inoperative. For this reason a second brake, on the same principle, but somewhat differently arranged, is adapted to the leading axle of the engine. For the ordinary working this axle would of course require no cog wheel, as it would merely carry the two side wheels running on the rails to support the weight of the machine. For the purpose of the brake, however, a cog wheel is added, engaging in the rack precisely like the driving one, and

keyed on to the axle; the two running wheels being loose, as before described. On to the intermediate parts of the axle are keyed two drums which revolve with the cog wheel, and to the circumferences of which clip brakes are attached, also worked by a powerful screw and handle, brought within reach of the enginemen. These brake arrangements are similar to those on the carriage axle hereafter mentioned, and which are shown in Fig. 11. For ordinary working, the clips being free, the axle revolves loosely by the engagement of the cog wheel into the rack; but when the brake is brought into action and the clips are tightened, the cogs are held up on the rack as in the former case, with sufficient power to stop the motion of the machine. The surfaces of the brake drums are not smooth, but are turned with wedge-shaped grooves to give better hold for the wooden brake blocks, which are cut to a corresponding form.

The third means of controlling the motion is certainly very ingenious and effectual, and—so far as the Author is aware—is novel. It is a peculiar mode of working the engine, adopted in running downhill, and it has the effect of offering a considerable resistance to the motion, whereby the force of gravity is, to a large extent, absorbed, and the speed thoroughly regulated. The way in which this is done is very simple. The steam is entirely shut off from the cylinders, and certain other cocks and valves are opened, by which the pistons are made to draw in atmospheric air, and to compress it on their return stroke before it is expelled. The degree of this compression can then be regulated so as to offer any resistance required, and thus, as the pistons are caused to move by the downward impulse of the gravity of the train, the velocity of their motion can be controlled at pleasure. The arrangements for this purpose are shown in Fig. 7. The valve gear is not reversed for the descent, but it is kept in forward motion, and hence, when the engine moves backward, the cylinders tend to draw in air through the exhaust pipe. This pipe is marked *d* in the Figure, and in the middle of it is fixed a box, containing two valves *g* and *h*. These are connected by a lever, so that when one is open the other is closed. The valve *g* is open during the forward or 'normal' working of the engine, and the exhaust steam is then allowed to pass upwards to the blast pipe in the usual way. But when the engine descends, the lever is reversed, the valve *g* is closed and the valve *h* is opened. A communication is thus formed with the outer air, and the air is allowed to enter the pipe, and is sucked into the cylinders as before described. The air thus drawn in is, by the return of the pistons, forced through

the valve boxes along the steam pipe *c* towards the boiler. But the communication with the boiler is shut off by the stop valve *a*, and thus the compressed air can find no exit except by a small cock *e*, the opening of which is regulated by a handle. If this cock is shut the air cannot get out, and consequently such a resistance is offered to the motion of the pistons as will suffice to stop the machine altogether. But by opening the cock in a suitable degree the compression and consequent resistance can be easily regulated to such an amount as will absorb the entire force of gravity, with the exception of so much as is just necessary to overcome the friction, and to give a speed of about 3 miles or 4 miles per hour.

It is calculated that a compression to about 4 atmospheres would produce this resistance. The space in the steam pipes and slide boxes acts as a sort of reservoir of compressed air to equalize the pressure and the flow through the exit cock. A little water is supplied to the cylinders during the descent, by a pipe from the tender, to prevent the pistons from working dry, and to keep the parts cool.

In the actual working the engine regulation is found sufficient of itself to control the descent; the brakes are always in readiness, but they are only used to stop the train, and at the moderate speed it is going, it can be brought to a stand almost instantaneously.

The precautions hitherto mentioned apply to the engine only; but it has been thought expedient to give the passengers an additional security, by a special safeguard attached to their carriage. One of the carriage axles is furnished with a cog wheel working into the rack, and with a clip brake apparatus, similar to that described for the leading axle of the engine, and worked by a handle (Figs. 10 and 11), within reach of a guard who always travels with the train.

In ascending, the carriage is not dragged behind the engine by means of a coupling, as on ordinary railways, but is pushed before it, being quite unattached. The objections to the pushing motion in ordinary trains do not apply in this instance, and there is this great advantage in the position named,—that if by any extraordinary concurrence of accidents the control over the engine, either in ascending or descending, should be lost, and it should run away down the incline, no harm need result to the carriage, for, being loose above the engine, its own brake can be put on, and it will be stopped where it is, even on the steepest part of the incline, till help can be procured.

In descending, the carriage still remains above the engine, following after it by its own weight. Hence there must be no places on the line quite level; but there must always be a slight fall towards the foot of the mountain. In consequence the road at the stations is made slightly inclined.

3. The danger of fracture of some part of the machinery will always be present, in this as in all other cases where machinery is used. But here again the slow speed is a guarantee against danger to the passengers. If the engine should become disabled as regards its exertion of power, it might probably still be safely lowered down by means of its brakes; or even if it were rendered incapable of motion, the worst that could happen would be that the passengers would have to get out and walk. Scarcely any fracture or accident short of explosion could, when the carriage is traveling at a speed of only 3 miles per hour, cause danger to life, seeing that it is protected from leaving the rails.

4. Derangements of the permanent way would be principally caused by the fall of stones and trees, the action of rain, and other unforeseen circumstances, which could only be guarded against by watchfulness. An accident is most to be feared from some small object getting between the teeth of the rack. It was one good feature of the design to form the teeth open, like a ladder, so as to give very small objects a chance of dropping through. For the rest, it is customary not only for men to patrol the line, but for a look-out guard either immediately to precede the train on foot, or to ride at its front point and keep a good look-out forward; when in case of any derangement being in sight, the progress of the train can be arrested till it is cleared away.

It is somewhat sad to have to mention that the chief derangements that have hitherto occurred have been willfully caused. The establishment of the railway has interfered materially with a large number of horse-keepers, porters, guides, and others, who have hitherto made a large plunder out of tourists ascending the mountain; these men and their hangers-on have of course borne no good-will to the new mode of conveyance, and some of them have carried their animosity so far as to endeavour to bring the railway into disrepute, by causing accidents upon it. Fortunately, however, the vigilance exercised has been effectual in preventing the occurrence of any mischance whatever.

On the whole, then, the Author believes that the safety of the railway is sufficiently established. Of its convenience and utility there can be no doubt, as it renders simple, easy, cheap, and expeditious, an excursion which formerly, though enjoyable enough

by the robust and enterprising, was often attended with considerable expense, inconvenience, and loss of time.

The fare charged for the ascent to Staffel is 5 francs, or about 1 shilling per mile; this is of course high when compared with the charges on other railways, but it gives a saving of 60 per cent. on the former modes of conveyance.

Half fare is charged for the descent. So many people prefer to walk down, as to render the traffic less in that direction. As the trains must return, the company offer an extra inducement to get them filled.

The ascent by railway requires only about one-third of the time occupied on horseback or on foot. This saving is of more importance than as regards the mere shortening of the journey, for it enables tourists to take advantage of the sudden changes of weather, which so often occur in these Alpine districts.

The railway is only worked for six months, or seven months in the year. During the winter it is closed. It has now been open for two seasons, and has been found to work well, no accident or interruption having occurred in the service.

The Engineer of the line, M. Riggenbach, has been so good as to furnish to the Author copies of the official reports of the railway, from which the following particulars are extracted:—

1. The total number of trips made, up and down, in the season of 1872, was 2,875; the total distance run was 14,273 kilomètres; and the number of locomotives in use was five.

2. The maximum number of trips in one day was 37; the maximum number of passengers in one month, August, was 15,461 up, and 14,354 down; the total number in the season, both ways included, about 87,000. The maximum receipts in one day was 5,840 francs.

3. The capital of the Company was £50,000, which sufficed for the first establishment of the railway; but the large development of the traffic has rendered necessary the doubling of $1\frac{1}{2}$ mile of the line, the provision of more stock, the erection of enlarged stations, workshops, &c., which have increased the outlay to about £60,000.

4. The gross receipts in 1872 were £15,105; the expenses, £3,420; leaving a net income of £11,685. Out of this, £3,000 was put by to a reserve fund, and a dividend of 15 per cent. was allotted to the shareholders.

As this speculation has been so successful, the inhabitants of the country on the opposite or north side of the mountain, jealous

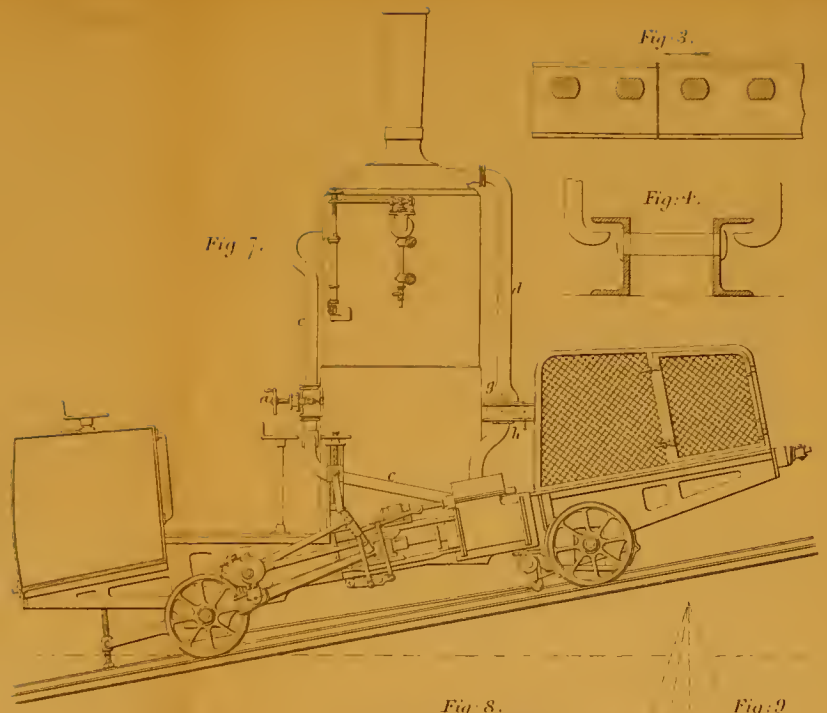

Fig: 7.



Fig: 3.



Fig: 4.

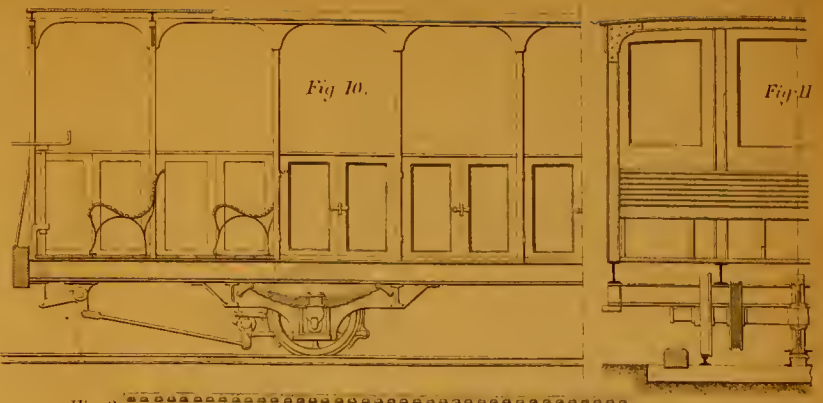

Fig: 10.



Fig: 11

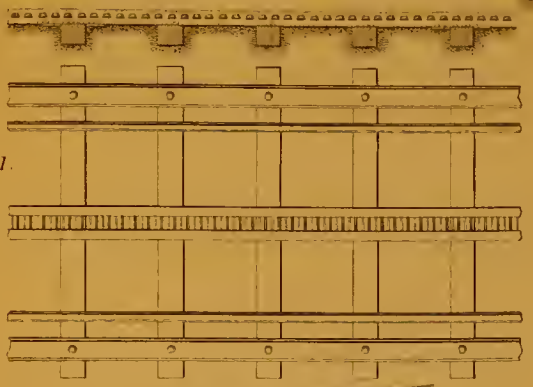

Fig: 2

Fig: 1.

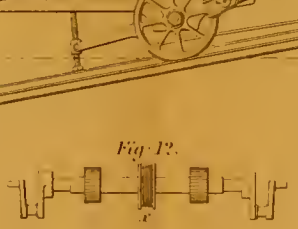

Fig: 12.

Fig: 8.

Fig: 9.

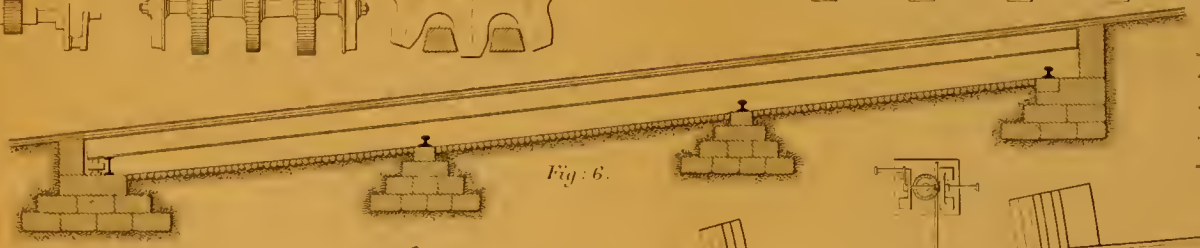

Fig: 6.

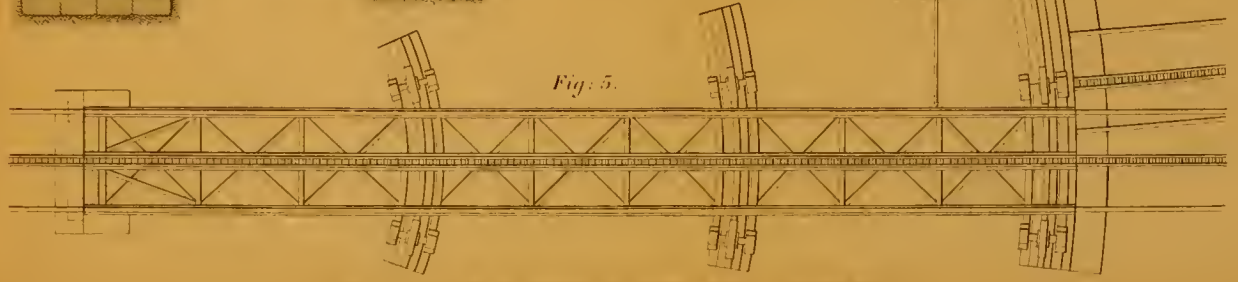

Fig: 5.

*Scale for Figures 1. 2. 7. 8. 10. 11. 1/50 the real size.*
*Scale for Figures 3. 4. 9. 1/10 the real size.*
*Scale for Figures 5 6. 1/100 the real size.*

of the Lucerne interest, have commenced the construction of a line of similar character from Arth, which will join the present railway at Staffel, the part from thence to the summit being common to the two.

The Paper is illustrated by a series of drawings and diagrams, from which Plate 18 has been compiled.

Dr. Pole said, he felt something like an apology was due for having presumed to bring before the Institution such a trifling matter as an account of a railway of only 3 miles or 4 miles in length. It, however, possessed some features of novelty. Railways were usually constructed either for dragging heavy loads at moderate speeds, or for conveying lighter loads at higher speeds. In the case of the Rigi railway the loads were light, and the speed was unusually slow, but there was a new feature in the extremely steep gradient of certain portions of the line, namely, 1 in 4. It was singular how little had been known in respect to that railway. Prior to his visit he had heard persons speak of it as a remarkable mechanical achievement, on account of its ascending by locomotive power the very steep side of a mountain; but the notions he had been able to obtain were so confused that he could not form any idea of its details. Under those circumstances he determined to examine it for himself, and was amply repaid for his trouble. He had been under the impression that in the descriptions he had previously received the steepness of the gradients had been exaggerated; but, on taking measurements for himself, he found that in several places the gradient was actually 1 in 4. He afterwards obtained some authentic particulars and some drawings, from which, aided by his own notes, the information now laid before the Institution had been compiled. Considering the extreme steepness, and the ingenuity of many of the arrangements, and, more than all, the financial success of the line, he trusted the description would prove interesting and useful.

With the aid of the diagrams, Dr. Pole gave further verbal illustrations of the arrangements described in the Paper, particularly of the various and multiplied precautions to insure safety, without confidence in which, as he explained, passengers would hesitate to trust themselves on the line. The sensation of running on such a steep gradient was peculiar, and, indeed, in descending, it was almost alarming, as in many places the train appeared to be going headlong into the lake, thousands of feet below; but the slowness and steadiness of the motion gave confidence in the security of the arrangements.

Mr. J. Hawkshaw, Past-President, said, he considered many of the details were ingenious; but the peculiar kind of rack used was a very old arrangement. It was one of the earliest things he recollected. When he was a boy he used to go and see Brandling's Colliery railway near Leeds, which was worked by a wheel with cogs, like that of the Rigi railway. The rack was fixed to the side of cast-

iron rails. In railways over mountainous districts, where great speed was not required, such an arrangement was a good mode of ascending steep gradients. The method adopted was evidently an adaptation of the system patented by Mr. Blenkinsop. The arrangements for the safety of the train were ingenious. The peculiar apparatus for checking the speed of the engine going down the incline was novel to him. To attain the same end, it was sometimes customary to reverse the engine, and that in great emergencies would be preferable, because the steam was then immediately thrown to the opposite side of the piston, and the speed in consequence immediately reduced. He understood that the object of having the carriage always pushed up before the engine was to give an additional feeling of security to the passengers. He did not, however, think it would make much difference, as regarded their actual safety, whether they were pushed up or pulled up. The Rigi railway seemed, on the whole, to display much constructive cleverness, and it did great credit to its Engineer.

Mr. Bramwell said, that both the Author and Mr. Hawkshaw seemed to consider the mode of regulating the descent of an incline by pressure on the engine pistons as new. Mr. Bramwell would call attention to a Paper read by Mr. C. W. Siemens, M. Inst. C.E., before the Institution of Mechanical Engineers on the 4th November, 1869, "On Le Chatelier's plan of using counter-pressure steam as a break in locomotive engines,"[1] in which a description was given of Le Chatelier's steam brake, called in France the 'contre-vapeur' system. Mr. Bramwell believed every engine on the Lyons railway was fitted with it. Le Chatelier's arrangement was to leave the steam regulator open, to reverse the engine, and to introduce a small injection of water into the cylinder to prevent the rise of temperature which would otherwise take place owing to the conversion of the power stored in the train into heat. The water thus injected was turned into steam, and was by the pistons pumped back into the boiler. This system had been tried on several railways in England with success, but it had not been generally used. At Mr. Bramwell's instance, Mr. Beattie allowed it to be tried on the London and South Western railway, and the result was very satisfactory. A train consisting of 16 carriages was employed, the weight of it was carefully ascertained, and a speed of 40 miles per hour was attained on a piece of perfectly

[1] *Vide* "Institution of Mechanical Engineers. Proceedings. 1870. Birmingham," p. 21.

level line. The steam was then shut off, and the train was allowed to come to rest without the use of the 'contre vapeur' or of any brakes. The distance required for the stoppage of the train was noted. The experiment was repeated by getting up the train to the same speed as before, but on that occasion the 'contre vapeur' system was applied to stop it. In a succeeding experiment the ordinary brakes were used, and in the final experiment those and the 'contre vapeur' were applied conjointly. It was found the train could be pulled up by the use of the 'contre vapeur' within the ordinary distance without the application of the brakes to the wheels. The use of the 'contre vapeur' was attended by the following advantages :—1, the momentum of the train was utilized in generating steam; 2, and what was of greater importance, the wheels could never 'skid' and wear flat places on the tires.

Indicator diagrams were taken during the trials, and a curious fact was observed, namely, that there was, whilst the 'contre vapeur' was at work, a great deal higher pressure of steam in the cylinders than there was in the boiler. The notion at first was, that either the indicator was out of order, or that there was some mistake in the experiment. An examination of the indicator and a repetition of the experiment showed that the explanation of the phenomenon was to be sought for elsewhere, and it then occurred to Mr. Bramwell that the rise of steam in the cylinder to a pressure above that in the boiler was due to the fact that the steam was acting as a steam ram in the same way that water is made to act in a water ram. In the particular engine with which the trial was being made there was a long steam pipe from the fire-box to the slide jackets; the engine being in reverse gear, the steam, on the port opening, had about one-half the capacity of the cylinder to fill at once. In that way an extremely rapid motion was set up in the long steam pipe, and then when the cylinder was filled, as it was in a small fraction of a second, with steam up to the boiler pressure, that motion could not be suddenly stopped, but was brought to rest gradually, but in coming to rest, it heaped into the cylinder a further quantity of steam, and thus raised the pressure in it above the pressure in the boiler. By that means the 140 lbs. pressure in the boiler became 150 lbs. pressure and upwards in the cylinder, as shown by the indicator. The 'contre vapeur' system was, in his judgment, most successful, and he did not know why it was not in use, inasmuch as he believed it would effect a large saving in the wear and tear, both of the rails and of the wheels of the carriages. It was desirable that the Author

should state why the power was applied to the hind wheels, so as to push the engine, rather than to the fore wheels, so as to pull it. Mr. Bramwell presumed there was some sound reason for the arrangement adopted.

Mr. G. Berkley said, the position of the driving wheels between the boiler and the tank for water and fuel was that which would naturally suggest itself. He should feel obliged if the Author would state how the cogs were riveted into the cheeks, and whether the full section of the cog passed through them. It would also be desirable the Meeting should be informed whether the action in ascending and descending had occasioned much wear upon the part of the cog which passed through the cheeks. Mr. Berkley would also ask whether the sleepers were laid on the rock, or were packed in the ordinary manner? The whole structure must evidently work as a machine, and consequently its parts must be built and maintained accurately in position one with the other, otherwise the railway would not have been worked with the safety which appeared to have been attained.

Mr. J. I. Thornycroft considered the Rigi railway to be a bold scheme well carried out. There were one or two points, however, on which he thought it desirable the meeting should have further information. He would inquire whether there was any difficulty experienced in keeping the carriage to the centre of the track? Owing to the wheels being loose on the axle, they would not have the same tendency as other conical wheels had of effecting that purpose. It would appear therefore that the rack must act as a guide to keep the train in position. He considered that pushing the carriage from behind—especially with the hinder wheels of the locomotive in going round curves—would cause the two carriages to assume a greater angle than that due to the curve on which they were moving, and thus produce a grinding action on the flanges of the wheels or on the rack.

Mr. J. T. Harrison said, it would appear that great attention had been paid to the efficiency of the engine; but, judging from the drawing (Plate 18, Fig. 10) the passengers' seats did not appear comfortable or well adapted for a line with gradients varying from 1 in 4 to 1 in 1,000. In order to make the seats at all comfortable, it seemed to him, some arrangement was required similar to that proposed in Mr. Fowler's steam vessel, namely, that the seats should be suspended so that the passengers might always maintain a perpendicular position.

Mr. James Brunlees said, the statement that out of the earnings, amounting to £15,105 per annum, the working expenses were only

£3,420 per annum,[1] appeared to him to be, at first sight, a most extraordinary result, and might lead people to infer that the steeper the gradients of a railway the better it would pay. But, he supposed, the explanation would be found in the slow speed at which the line was worked, and the high fares charged.

With regard to the mechanical appliances available for ascending very steep gradients of, say, from 1 in 4 to 1 in 12, he considered that, with a tolerably straight line, fixed engines and a rope would be the most effective for the conveyance of the greatest amount of traffic at the least cost. The rack, as worked on the Rigi, was, however, well suited for a tortuous line on similar gradients, and from it a greater effective result could be obtained than from any other application of locomotive power. For gradients ranging from 1 in 12 to 1 in 25 he believed the centre rail system would be found to give the best results. The trials of a centre-rail engine at Whitby last autumn proved that the adhesion gained from the horizontal wheels fully equalled that obtained from the ordinary vertical wheels, thus making the engine equal in effect to one of twice the weight.

The use of back pressure on the pistons for providing the brake power necessary for holding the trains whilst going downhill was not novel, inasmuch as it was adopted some years since on the Mont Cenis Summit railway on the descent from Grande Croix to Susa, a distance of 12 miles, on an average gradient of 1 in 14. In that case both cylinder cocks were opened, and the reversing lever put into back gear, in the first or second notch from the centre. To prevent the cylinders from heating, a small jet of water from the boiler was introduced through a $\frac{1}{4}$-in. pipe, regulated by a cock worked from the foot plate. About one-third of the brake power required was obtained by the use of the back pressure, and the proportion could be increased to one-half or more by putting the reversing lever farther into back gear.

Dr. Pole, in reply, said that, with regard to the 'air brake' in use on the Rigi railway, he thought the chief novelty was in the use of atmospheric air, and in the mode of regulating it with a cock, by which the velocity of exit of the compressed air could be regulated to a great nicety, thus insuring perfect control over the engine. The speed with which the air escaped from the cylinder effected the control of the train. He saw the driver when the engine was going a little too fast touch the cock handle a little, and instantly the speed was checked.

[1] *Vide* ante, p. 116.

The teeth of the rack were cut from a rolled bar, and the ends, having had the corners rounded off to make a shoulder, had been riveted firmly in the cheek plates—so firmly that he did not think that any yielding would take place. He believed the principal fear of the designers was that of the tooth tearing itself out of the cheek plate, and that had been provided against, as described in the Paper.[1] The sleepers did not rest entirely on ballast, for it would not do for the permanent way to be subject to those slight variations, which comparatively were of no practical effect on an ordinary line. The designers went back to the system, now abolished on ordinary railways, of rigidity. The sleepers were supported at intervals upon masonry foundations carried up from the rock. The intervals were then filled in with ballast; but the sleepers really rested upon a rigid foundation.

There was no difficulty that he was aware of in keeping the carriages in the centre of the track; and he believed that at the slow speed adopted no inconvenience arose from any difference of angle between the carriages and the curve round which they were running. The form of the seats best adapted to the comfort of the passengers—like every other point which had a practical bearing—had been studied by the Swiss, and their reasons for adopting the form selected would be obvious to any one who considered the statical arrangements involved.

With regard to the disproportion of expenditure to receipts, it might be accounted for by the very high fare charged—about 1*s.* per mile. The persons who used the railway willingly paid it, inasmuch as it was not half the expense of going up on horseback; and they would rather pay that high fare than ascend on foot. Since the expenditure was only of the ordinary kind, that would account for the great disparity between receipt and expenditure. The figures given in the Paper were taken from the returns made to the shareholders, which he supposed might be depended on.

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[1] *Vide* ante, p. 108.

May 6, 1873.

T. HAWKSLEY, President,
in the Chair.

The following Candidates were balloted for and duly elected:—FRANCIS HENRY ASHHURST, Stud. Inst. C.E., WILLIAM TEMPLE BOURNE, PETER JOHN BRUFF, THOMAS ALFRED BULKLEY, WILLIAM LUNDY CRAWFORD, THOMAS CHARLES ELLIS, Stud. Inst. C.E., RICHARD GERVASE ELWES, EDWARD FIELD, ARCHIBALD HENRY FORD, Lieut.-Col. HENRY WILLIAM GULLIVER, R.E., SAMUEL HARPUR, LINDSAY HEATH, Stud. Inst. C.E., JOHN KYLE, EDWARD JAMES LYNCH, ROBERT KNOX MACBRIDE, FRANCIS DAWSON MITCHELL, CHARLES PROUSE, Jun., ALFRED EWALD SCHMID, JOHN SMITH SWORDER, JOHN LEWIS FELIX TARGET, THOMAS VERNON, and OLIVER YORK, as Associates.

It was announced that the Council, acting under the provisions of Sect. III., Cl. VII., of the Bye-Laws, had transferred ISAAC LOWTHIAN BELL, ARTHUR SAMUEL HAMAND, and ANTHONY HENRY KESSNER from the class of Associates to that of Members.

Also, that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution:—ARTHUR ERNEST BALDWIN, ROBERT EDWARD DUNSTAN, and WALTER THOMAS.

No. 1,344.—"The River Clyde." By JAMES DEAS, M. Inst. C.E.[1]

PROBABLY for no river in Great Britain has so much been done "by art and man's device" as for the river Clyde, above Port Glasgow. In fact, from a mile below Bowling upwards to Glasgow, a length of 12 miles, the Clyde of the present day is nearly as much an artificial navigation as the Suez Canal. It requires constant dredging to maintain its depth; and the ever increasing size of the vessels of the mercantile navy necessitates the continued deepening of the river to enable the navigation to keep pace with the demands of the shipping trade. Even so recently as one hundred years ago the river

[1] The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

was almost in a state of nature, and was fordable on foot at Dumbuck Ford, more than 12 miles below Glasgow.

In this Paper it is proposed to give, as concisely and shortly as possible, a history of the navigation, and to describe briefly the character of the various engineering works which have converted the Clyde from a shallow stream, fordable at many points between Glasgow and the sea, into a noble river, capable of bearing on its waters the commerce and ships of all nations. The navigable facilities thus realised, combined with the mineral resources of the district, have raised Glasgow from an insignificant provincial town, having, in 1771, a population of only 35,000, to be the second city of the empire, with a population of 566,150, inclusive of that of the immediate suburbs, according to the census of 1871, and have made its banks the seat of the largest ship-building trade in the world. Seldom has engineering skill been productive of so much commercial success; perhaps never has it contributed more to individual prosperity than it has done in the improvement of the river Clyde.

To make the Paper of greater practical value, the modes of dredging and depositing, adopted in carrying out the improvements, will be described, and details will be given of the cost of those operations.

The river Clyde rises in the south of Lanarkshire, from the same hill range—on the confines of Lanarkshire and Dumfriesshire, near Moffat—that gives birth to the rivers Tweed and Annan. It is 98 miles long, drains an area of 945 square miles, and discharges into the Atlantic Ocean; its ordinary rate of discharge—upon the authority of Mr. John F. Ure, M. Inst. C.E.—being 48,000 cubic feet per minute. It flows, in its progress, over the famous falls near Lanark, and past the towns of Lanark, Hamilton, Rutherglen, Glasgow, Renfrew, Dumbarton, Port Glasgow, and Greenock, and numerous villages; among others, Bothwell, Blantyre—where the celebrated traveler, Livingstone, worked as a mill-spinner—and Uddingston. In its upper reaches it flows through rich pastoral lands, in its middle reaches through fertile holms and prolific orchards, and in its lower reaches through valuable mineral fields and busy seats of industry and commerce.

## Successive Improvements.

In 1566, the first crude attempt was made to improve the river by detachments of the inhabitants of Glasgow, Renfrew, and Dumbarton endeavouring to open up a formidable sand bank at Dumbuck,

above Dumbarton, at which they laboured for several weeks, residing, during the time, in temporary huts, built on the river banks, near the scene of their operations. It is presumed that similar attempts were made for a series of years, but apparently without much success, as for several years, prior to 1658, the shipping port of Glasgow was in Ayrshire. As the passage of lighters from that distant place was tedious, and land carriage expensive, the Magistrates of Glasgow in that year made overtures to the Magistrates of Dumbarton for the purchase of ground for an extensive harbour there, which the latter declined to entertain, on the ground:—"that the great influx of mariners and others would raise the price of provisions to the inhabitants." Disappointed in this project, the Magistrates of Glasgow turned their attention to the opposite side of the river, and, in 1662, purchased 13 acres of ground, on which they laid out the town of Port Glasgow, built harbours, and constructed the first graving dock in Scotland. Still desirous to have accommodation at Glasgow, they, in 1688, built a quay at the Broomielaw, at the cost of £1,666 13*s.* 4*d.*; but, even in 1740, little had been done in deepening the river, as the following Minute of Council, dated 8th May, 1740, will show:—"Which day, &c., the Councill agree that a tryal be made this season of deepening the River below the Broomielaw, and remit to the Magistrates to cause do the same, and go the length of £100 sterling of charges thereupon, and to cause build a flatt-bottomed boat, to carry off the sand and chingle from the banks."

The conviction seems to have grown stronger year after year in the minds of the Magistrates that the progress and prosperity of the city depended very much on the improvement of the river; and, in 1755, they set about it in earnest by employing Smeaton, followed, in 1768, by Golborne, and, in 1769, by James Watt, to report to them on the subject; and they showed a determination to secure the best possible advice by employing Rennie in 1799, in 1807, and in 1809; and Telford in 1806, in 1819, in 1821, and in 1826. Since then engineers of the highest eminence have been consulted as to the further improvement of the river.

The report by Smeaton, dated 3rd September, 1755, contains much interesting and curious information. In it he notes that, of the twelve different shoals between Glasgow and Renfrew, "the two shoalest places" were at Pointhouse Ford, now the western boundary of the harbour of Glasgow, where the river was 1 ft. 3 in. deep at low water, and 3 ft. 8 in. deep at high water; and at

Hirst, now within the harbour, where the depth was 1 ft. 6 in. at low water, and 3 ft. 3 in. at high water, there is now 14 ft. at low water, and 24 ft. at high water, at each of those places. He mentions that ordinary neaps were 'sensible' at Glasgow, and so little appreciation had he of the future of the river as a navigation that he recommended that a lock and dam should be constructed at Marlin Ford, 4 miles below Glasgow Bridge, in order to secure 4 ft. 6 in. of water at all times up to the quay at Glasgow, and he gives at great length his reasons for the recommendation. He proposed that the lock should be "18 ft. in the clear, and to take in a vessel of 70 ft. long, or to let pass a sloop or brig of above 100 tons, when there is water in the river to admit it."

Fortunately for Glasgow, no lock and dam were constructed. Nothing seems to have been done until 1768, when Mr. John Golborne, of Chester, visited the Clyde, and inaugurated the system of contracting the river by the construction of rubble jetties, and the removal of the gravel shoals by dredging or ploughing, which effected the first marked improvement of the navigation. Mr. Golborne, in his first report, gives the depth at Hirst Ford as only 1 ft., and goes on to say :—

"The River Clyde is at present in a state of nature, and, for want of due attention, has been suffered to expand too much; for the sides in most places being much softer than the bottom, the current has operated there, because it could not penetrate the bed of the river, and has, by those means, gained in breadth what is wanting in depth."

"I shall proceed on these principles of assisting nature when she cannot do her own work, by removing the stones and hard gravel from the bottom of the river where it is shallow, and by contracting the channel where it is worn too wide; for quantities of sand brought down by the spates form banks in the channel, to the great detriment of the navigation. The first and grand obstacle is Dumbuck Ford (12 miles below Glasgow Bridge), where, the river dividing itself into two channels, the reflowing current is greatly weakened, and the bottom, being covered with a crust of hard gravel, cannot be worn down to a proper depth; but if a jetty were extended over the south channel, to confine the current, and the hard crust of gravel removed by dredging, the reflowing current would then act with greater force, and soon grind down a deep and capacious channel."

"By these means, easy and simple in themselves, without laying a restraint on nature, I humbly conceive that the River Clyde

may be deepened so as to have 4 ft., or perhaps 5 ft. depth up to the Broomielaw at low water."

Further on he says:—"When the river is confined to a proper breadth by jetties, the intermediate spaces will be filled up with sand carried down by spates and the fitts brought by the tides, and become firm land." And he concludes this part of his report by giving the following estimate of the expense, which, from its moderate character, the Author thinks deserves to be put on record:—

"An Estimate of the Expense of Improving the Navigation of the River Clyde.

| | £ |
|---|---|
| "To contracting the river with jetties, being eight miles, at £400 per mile | 3,200 |
| To extending a jetty from Longoch Point over the south channel | 1,260 |
| To contracting the channel at Kilpatrick Sands | 1,000 |
| To dredging and deepening Dumbuck Ford | 500 |
| To dredging and deepening the other fords | 1,000 |
| To building three sets of ponts to carry stones, at £80 each | 240 |
| To 20 per cent. on the whole, for unforseen events, utensils, and engines | 1,440 |
| Total | £8,640 |

In 1769, James Watt, by the desire of the Magistrates of Glasgow, examined the declivity of the bed of the river Clyde from the Broomielaw Quay to Dumbuck Ford, below Bowling, according to Mr. Golborne's directions, and made a report of the depth at low water of the river at numerous places between Glasgow and Dumbuck Ford. At Hirst Ford, harbour of Glasgow, he found the depth 14 in., and at Dumbuck Ford, a depth of 2 ft.

In 1773, Mr. Golborne took a contract to make Dumbuck Ford 6 ft. deep and 300 ft. wide, at low water, for £2,300; and on the 19th of September, 1775, the Town Council—on the recommendation of the merchants—gave him £1,500 for deepening the river 10 in. more than he was bound to do by his contract, presented him with a silver cup, and gave his son £100.

In 1781, thirteen years after his first visit, Mr. Golborne again inspected the river at the request of the Magistrates, who, he says in his report, were "desirous to know if a greater depth of water could be brought to the Broomielaw Quay, so as to receive vessels trading to England and Ireland;" and he reports that it gave him

"great pleasure and satisfaction to find the general work in such good order and condition, and that the spaces between many of the jetties were filled up and covered with grass, to the great emolument of the proprietors and advantage of the river." And as the result of deepening Dumbuck Ford, he says:—"It gave me great pleasure to observe the channel at Dumbuck has considerably increased its depth since I removed the ford," and that, "on sounding it, with the Magistrates, on the 8th day of August, 1781, at low water, we had the pleasure to find no less than 14 ft.; for the jetty which I had carried over the south channel turned the current so effectually down the north channel, and the machines which I have used having cut through the stratum of clay into the sand, it was in many places from 20 ft. to 22 ft. deep."

Rennie followed Golborne; and, in 1799, recommended the shortening of some of the jetties, the lengthening of others, and the construction of new ones, "so as to direct the channel in its proper course with the least obstruction to the water;" also the building of low rubble walls from point to point of the jetties, so as to render the channel uniform, and prevent the accumulation of shoals which he found had taken place between the jetties. Upwards of 200 jetties, varying in length from 50 ft. to 550 ft., were erected between Glasgow Bridge and Bowling. These, while they effected a considerable deepening of the navigation, did, as Mr. Golborne expected, reclaim land to the proprietors, from the alveus of the river. Much of this land has since been purchased back, at great cost, for the subsequent widening and other improvements of the navigation.

The next recorded report the Author can find bearing on the improvement of the river is dated Glasgow 24th May, 1806, and is made by Thomas Telford.

He arranged his opinions under three heads:—

1. The leading or bringing up a greater quantity of tide water.
2. The advantages to be derived from having a tracking or towing path on a part of the river.
3. Forming a harbour at the Broomielaw.

Under the first head, he says:—"That, in order to obtain a greater quantity of tide water in the upper part of the river, the general principle is, to reduce the bed of the river to that form which shall afford the most direct course, oppose the fewest obstacles, and render the friction the least possible in regard to the section of the

flowing water." He expresses the opinion that the "projecting jetties from each shore, for a considerable way into the river, is a very imperfect and improper means of attaining the object in view," and he recommends, for the purpose of bringing the river "into the most perfect form," the completing of the parallel dykes begun on the recommendation of Rennie, and the bringing of the river to an uniform width. Mr. Telford notes, as an interesting circumstance, that "on the 14th February last, Mr. Archd. Wilkie, master of the 'Harmony' of Liverpool, then lying at the Broomielaw, informed me that he came up with ordinary spring tide, drawing 8 ft. 6 in. of water:" he adds that this was a vessel of 120 tons burthen.

Under the second head, he says:—"I find that, in navigating the river, vessels can come as far as Renfrew, with light winds; but the plantations near to Elderslie, by taking off the winds, frequently check the course of the navigation by leaving the vessels becalmed," and recommends, "that to render the navigation uniform and expeditious, a path should be completed, and horses applied to tracking this district." A towing path, 20 ft. wide, was accordingly constructed on the south side of the river, all the way from Glasgow to Renfrew—a distance of 5 miles—and it continued to be much used until the advent of the steam-boat rendered its use for that purpose unnecessary. It now forms a valuable right-of-way to the public for foot-passenger traffic.

Under the third head—forming a harbour at the Broomielaw—Telford disapproves of the extension of the then-existing and only accommodation for vessels loading and discharging, namely, the quays along the river; and recommends the conversion of "a portion of the present bed of the river into a wet dock," and the making of a new channel to the southward. This advice was not followed; but instead, as the traffic increased, quays were extended along both sides of the river.

In 1807, in an exhaustive report, Rennie gave the widths he proposed the river to be:—

| | | | |
|---|---|---|---|
| At Dumbarton Castle . . . . . | 696 ft. | It is now | 1,000 ft. |
| At west end of Bowling Bay . . . . | 504 „ | „ | 400 „ |
| At entrance to Forth and Clyde canal . . | 440 „ | „ | 590 „ |
| At mouth of river Cart . . . . . | 280 „ | „ | 500 „ |
| Just above „ . . . . . | 240 „ | „ | 500 „ |
| At Renfrew Ferry . . . . . | 230 „ | „ | 410 „ |
| Just below mouth of river Kelvin, which is now the lower boundary of the harbour of Glasgow . . . . | 180 „ | „ | 370 „ |
| In the harbour . . . . . | 135½ „ | „ | 450 „ |

From 1807 till the end of 1835, when Mr. Walker was appointed Engineer, deepening, widening, and straightening seem to have been continuously carried on ; and in his first report to the Clyde Trustees, dated February, 1836, he states that :—"there is now at the Broomielaw from 7 ft. to 8 ft. at low water, while the lift of a neap tide at Glasgow Bridge—which was only sensible in 1755—is 4 ft., and of a spring tide, 7 ft. or 8 ft., making 12 ft. depth at high water of a neap, and 15 ft. of a spring tide; so that the river which, by artificial means, was to be rendered capable of taking craft of about 30 tons or 40 tons to Glasgow, has, by what Golborne calls 'assisting nature,' been rendered capable of floating vessels nearly ten times the burthen."

In 1837, Mr. J. Scott Russell, M. Inst. C.E., at the instance of Sir Thomas Brisbane, Bart.—then President of the Royal Society of Edinburgh, and formerly President of the British Association for the Advancement of Science—and with the co-operation of the Clyde Trustees, spent several weeks in carrying out a most minute and elaborate series of observations on the tides of the Firth of Clyde, and furnished the latter body with a valuable report, not only giving a table of tides, but also his opinion on the future improvement of the river. At that date spring tides rose and fell about 11 ft. at Port Glasgow, and about 7 ft. at Glasgow. The tides now rise about the same at Port Glasgow, but at Glasgow, springs rise $10\frac{1}{2}$ ft., and neaps rise $9\frac{1}{4}$ ft. Then the time of high water was 1 hr. 23 mins. later at Glasgow than at Port Glasgow, now it is only 1 hr. 5 mins. In the beginning of the present century it was 3 hrs. later at Glasgow than at Port Glasgow. In his report, Mr. Scott Russell predicted that if the depth of the river was increased sufficiently, high water would be obtained at Glasgow within an hour after it reached Port Glasgow ; and his prediction has at length all but been fulfilled. The time of low water at Glasgow is at present 1 hr. 40 mins. later than at Port Glasgow. In the harbour of Glasgow the tide flows for about 5 hrs. 40 mins., and ebbs for about 6 hrs. 50 mins. At Port Glasgow it flows for about 6 hrs. 15 mins., and ebbs for about 6 hrs. 2 mins. In the Appendix are given tables of the readings of the tide-gauges, at seven different stations between Glasgow and Port Glasgow, of the spring tide of the 11th of April, 1872.[1] Plates 22 and 23 have been compiled from these readings.

[1] *Vide* Appendix, I, p. 154.

In November, 1839, parliamentary plans, prepared by Mr. Walker, were deposited, which dealt with the whole river under the jurisdiction of the Trustees, and on which defining lines for both sides of the river were laid down. These lines were approved of, and an Act to carry out the work in accordance therewith was passed by Parliament in 1840; and upon them—with very slight modifications at one or two places, to meet the wishes of riparian proprietors—the improvements of the river have since been carried out.

Notwithstanding the great improvements effected previously to the passing of that Act, the parliamentary plans of 1839 show that, even so recently as then, the width of the river above Napier's Dock, in the harbour of Glasgow, was only 168 ft. It is now 410 ft., and vessels of 3,000 tons burthen can float where, at that time, stood one of the largest cotton-mills then in the city.

| | | |
|---|---|---|
| At Napier's Dock the width of the river, in 1840, was . . . . . | 150 ft. | It is now 490 ft. |
| At Finnieston Quay, in 1840, it was . . | 160 „ | „ 400 „ |
| At Renfrew, in 1800, it was . . . . | 340 „ | |
| „ in 1840, it was . . . . | 245 „ | „ 410 „ |
| At mouth of River Cart, in 1800, it was . | 800 „ | |
| „ „ in 1840, it was . . | 275 „ | „ 500 „ |

Plate 21 shows the harbour of Glasgow in 1800, in 1840, and in 1872. The straightening and widening have been effected gradually. In the harbour in 1755, the depth at low water was only 1 ft. 6 in. In 1830, vessels of 15 ft. draught; in 1839, of 17 ft. draught; in 1854, of 19 ft. draught; in 1861, of 20 ft. draught; in 1862, of 21 ft. draught; and in 1870, of 22 ft. draught were safely navigated to and from Glasgow. Until within the last few years vessels of 15 ft. draught and upwards were two, and often three, tides in the river in their passages up and down, being—from the shallow state of the channel—afloat for only an hour or so before, and after, high water; now vessels drawing 22 ft. leave Glasgow 2 hours to 3 hours before high water, and get to sea in one tide.

The improvements carried out on the river, since 1758, have resulted in the gradual lowering of the level of low water in the harbour of Glasgow to the somewhat remarkable extent of 8 ft. Since 1853, the depression of the level has been fully 13 in. This recent depression is, in the Author's opinion, chiefly due to the great extent to which deepening, widening, and straightening have been carried on in recent years in the lower reaches of the river, thereby enabling the ebb tides to get out to sea with much

greater facility than formerly. The level of high water of ordinary spring tides is now about 10 in. higher than in 1853.

From the irregular and tortuous character of the river, and the shoals existing in its bed, the low-lying portion of the city, along both sides, periodically suffered severely in former years from the river overflowing its banks. Rennie reported very fully on the subject in 1799, and in 1807, and Walker in 1836. The straightening of the river, and the enlarging of its sectional area, have put an end to all inundations; the last time the river was over the quays in the harbour of Glasgow being in 1856.

The consequences of the acceleration of the ebbing of the tides are, however, not entirely beneficial. The levels of the foundations of the quay walls built even as late as 15 years to 20 years ago, are now in most cases much too high to suit the altered level of low water, and the continuous demand for increased depth of water to suit the class of large vessels now built. It will readily be understood, therefore, that these walls have evinced a tendency to slip into the river; and that, to counteract this, the attention of the Engineers who have in recent years had charge of the works has been much directed. It would occupy too much of this Paper to describe the character of the quay walls of the harbour of Glasgow, and the nature of the works carried out to strengthen such as showed signs of giving way; but the Author hopes he may yet have the privilege of submitting to the Institution a Paper on the subject.

The improvement of the Clyde, while it has been of great national importance, and has conferred immense benefits, not only on the district through which it runs, but on the world at large, has destroyed one industry which once flourished on its banks—salmon-fishing, as a trade, above Dumbarton Castle, is extinct. The rights of salmon-fishing in the river were carefully protected in the earlier Acts of Parliament; and fishing stations were numerous, and of much value—one station, with its hut, being within the precincts of the harbour—but the 'whir' of the paddle, the 'churn' of the screw, and, above all, the sewage from the vast population in the area which the river drains, together with the deleterious liquid refuse from numerous manufactories of all kinds, have driven away that much-prized fish.

Even at the present time the Clyde Trustees pay upwards of £200 annually to the burgh of Renfrew for damage to their salmon-fishings. The fishing rights of this royal burgh, from which His Royal Highness the Prince of Wales takes his title of Baron Renfrew, were very extensive, extending on the south side of the

river from Marlin Ford, 4 miles below Glasgow Bridge, to the Cloch Stane, about 6 miles below Greenock, and 27 miles below Glasgow.

### Docks, Quayage, &c.

Although docks were, at the instance of the Magistrates, reported on and recommended by Telford in 1806, and in 1819; by Rennie in 1806, and in 1807; by Clark in 1824; by Hartley in 1834; by Logan in 1835; by Walker in 1836, in 1849, in 1853, and in 1855; by Bremner in 1849; and by Ure in 1854, and in 1855; and although Acts of Parliament were obtained for their construction in 1840, and in 1846, the sides of the river afforded, until a recent date, sufficient scope for quay extension; and it was not until 1867, that the only dock yet constructed at Glasgow was opened. It is a tidal dock, having $5\frac{1}{3}$ acres of water space, and is surrounded with a timber wharf giving 830 lineal yards of quayage.

The unoccupied ground for quayage along the banks of the river, within the limits of the harbour of Glasgow, being now well nigh exhausted, the Trustees, in 1870, obtained an Act of Parliament to construct docks at Stobcross on a much larger scale than those authorised in 1846, and the work has been begun. These docks will have a water area of nearly 30 acres, upwards of 30 acres of quayage, 3,100 lineal yards of quays, and they will accommodate 1,000,000 tons of shipping per annum; the estimated cost, including land, is £1,163,000.

There is as yet no public graving dock on the river Clyde above Port Glasgow, but the Clyde Trustees are constructing one at Glasgow for which they obtained an Act in 1868. It will be 560 ft. in length within caisson, 72 ft. in width of entrance, and it will have 22 ft. depth of water at ordinary spring tides.

In 1856, Messrs. Tod and McGregor, engineers and ship-builders, had the enterprise to construct a graving dock—in connection with their extensive works—500 ft. in length, with an entrance 56 ft. wide. At Dumbarton, there is another private dock 300 ft. long, with an entrance 41 ft. wide. A graving dock has existed at Port Glasgow since 1762, and it is now being lengthened to 310 ft. It was constructed from the designs of James Watt. Greenock possesses five graving docks, Ardrossan has one graving dock, and at Troon there are two graving docks. Details regarding these various graving docks are given in the Appendix.[1]

[1] *Vide* Appendix, II., p. 155.

In the Appendix will also be found a table, showing the progressive lengths of quays, areas of harbour, depths of water in harbour, maximum draft of vessels, total registered tonnage, registered tonnage worked per lineal yard of quay wall, registered tonnage worked per acre of water space, total tonnage of goods, tonnage worked per lineal yard of quay wall, total revenue, total receipts per lineal yard of quay wall, customs' revenue collected at Glasgow, and population of the city.[1]

The length of the quayage in the harbour of Glasgow at the present time is 5,604 lineal yards; 2,782 lineal yards are on the north side, and 2,822 lineal yards on the south side, of the river; 400 yards on each side of the river are also under contract, and nearly ready for use. The area of the existing quayage, including quays under construction, is 193,000 square yards, or about 40 acres, of which 68,800 square yards, or nearly 14¼ acres, are covered with sheds. The water space of that portion of the river surrounded by quays or wharves is about 70 acres.

There is one 60-ton crane, one 40-ton crane, one 30-ton crane, and numerous smaller steam and other cranes. The gross revenue from cranes last year was £4,752, from weighing-machines, £1,319, and for the use of gangway planks, £1,309.

The Clyde Trustees have six ferries across the river within the precincts of the harbour of Glasgow; one across the mouth of the river Kelvin, at Govan, and one at Whiteinch, about a mile below the western boundary of the harbour of Glasgow. The gross revenue from the eight ferries was, in 1872, upwards of £10,000. Four of the six ferries in the harbour of Glasgow are wrought by steam, and two by row-boats; five are for passengers only, and the steam ferry at Govan is for carriages, carts, horses, and passengers, and is wrought by a chain extended across the river. The ferry across the mouth of the river Kelvin, and the ferry at Whiteinch, are row-boat ferries. Exclusive of Clyde Trust officials, customs officials, police constables, pilots, and others who are carried free, 7,604,942 passengers crossed the various ferries during the year 1872, or at the rate of 20,835 per day.

The principal passenger ferry is Clyde Street Ferry. It is open day and night; from 5 a.m. to 11 p.m. the service is by steam-boat, and from 11 p.m. to 5 a.m. by row-boat. The steam-boat, which is licensed by the Board of Trade to carry 60 passengers, is worked in two shifts by a crew of three men in each shift—an

[1] *Vide* Appendix, III, p. 156.

engineer, steersman, and deck hand. It crosses the harbour on an average 270 times during each day of 18 hours, or 1 trip every 4 minutes. The number of paying passengers who crossed by the steam-boat during the year ending 31st December, 1872, was 2,074,364, giving a daily average of 5,683; and by row-boat 77,656, giving a nightly average of 213. The steam-boat is 44 ft. 8 in. extreme length, by 13 ft. 3 in. breadth over the belting at the centre, and 4 ft. 6 in., breadth at each end. It draws 3 ft. 1 in. when fully loaded. It is screw-propelled by an 8-H.P. engine placed amidships, and runs end on without 'canting,' to the stairs at each side of the harbour.

There are two other steam ferries for carriages, carts, horses, and passengers across the river Clyde, besides the one at Govan, namely, one belonging to the Burgh of Renfrew, at Renfrew, and one belonging to Lord Blantyre at Erskine; they are both wrought by chains across the river.

### Bowling Harbour.

In 1768, an Act was passed for the construction of a navigable canal from the river Forth, near the mouth of the river Carron, to the river Clyde, near Bowling, to be called the Forth and Clyde Navigation, and, in 1775, the canal was opened for traffic. Previously to 1846, the only connection of the canal with the Clyde was direct from the river by means of a lock, but in that year the proprietors of the navigation obtained parliamentary authority for the construction of an outer basin, or harbour, at Bowling Bay, and wharves or quays in connection therewith, with a lock to connect the proposed harbour with the canal, and the works were shortly afterwards executed. The area of the Canal Company's basin is about 3½ acres, having 390 lineal yards of quayage and wharfage inside the basin, and 196 lineal yards facing the river. The Clyde Trustees, about the same time that the Canal Company formed this basin, erected a wharf immediately below its entrance—on the line of the training dyke inclosing Bowling Bay—for the use of vessels of deep draught, while waiting the flowing of the tide. In 1856, they raised the training dyke to about 8 ft. above the level of high water, and closed in the lower end of the bay with a dyke of the same height; and greatly deepened the bay inside. A tidal basin of 8½ acres was thus formed, which every winter is full of river steamers and other craft laid up for the season.

### Beacons, Buoys, and Lighthouses.

The deep water channel below Dumbarton Castle is carefully

defined by beacons and buoys, and in recent years the practice of navigating the river during the night having much increased, the additional facilities of lighthouses and cast-iron light towers have been provided.

Three light towers on the banks above Bowling, mark bends in the course of the river; about a mile below Bowling, a lighthouse has long existed on the south side of the deep-water channel; a lightship, on the same side, sheds its welcome rays along the channel in the estuary about a mile below Dumbarton Castle; and the north side of the channel, a short distance above Port Glasgow, is marked by Cardross Lighthouse. All these are maintained by the Clyde Trustees.

Below Port Glasgow the channel and estuary are under the care of the 'Clyde Lighthouses Trust,' who light and buoy the Firth as far as the Cumbrae Heads, opposite the Island of Bute. The first Act incorporating this important trust was passed in 1756. By it they were empowered "to erect, or cause to be erected, on the summit, or south-west end of the Island of Little Cumray, a proper lighthouse, with such other buildings and conveniences as to them shall appear necessary; and also to erect, or cause to be erected, a breast, or wharf, on the Firth of Clyde, upon the said island, for landing coals for burning in such lighthouse." This Act likewise gave the Lighthouse Trustees power "to remove, or cause to be removed, such shoals and flats in the Firth of Clyde; and to erect and fix, or cause to be erected and fixed, such beacons, buoys, land or sea marks, on any place or places in the said Firth, as they shall judge expedient, for rendering the navigation more safe and commodious." The old fire-lamp has long since given place to a first-class stone lighthouse, with all modern improvements; and a Daboll's fog-horn, worked by an atmospheric engine, was erected, in 1866, in close proximity to the lighthouse.

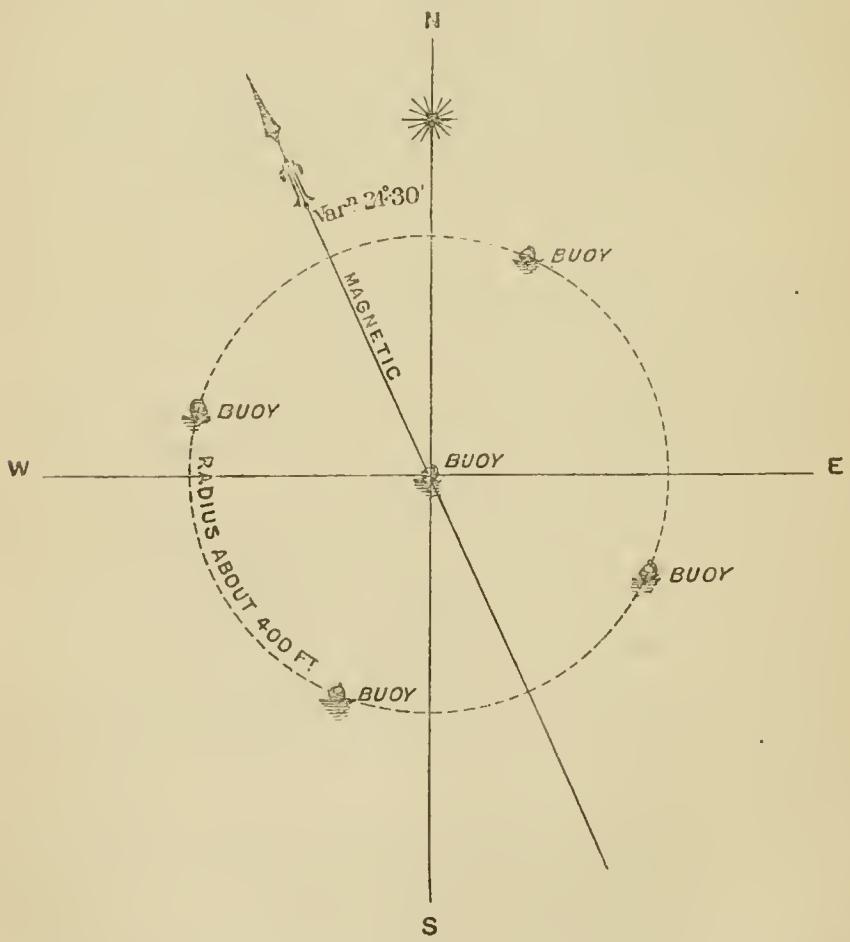
The Trust have also erected similar lighthouses at Toward Point, below Dunoon, and at Cloch, below Gourock; a timber and iron lighthouse at Garvel Point, above Greenock; and two light towers at Port Glasgow.

### Swinging Buoys for Adjusting Ships' Compasses.

By the Act of 1858, the Trustees obtained authority "to construct, moor, and place buoys in such place in the river, Firth, or estuary of the Clyde, as shall be fixed upon by the Commissioners of Northern Lighthouses as most suitable and convenient for

vessels navigating the river, if the said commissioners are of opinion that the placing of such buoys is expedient on public grounds, and to maintain, manage, and keep in repair, and from time to time to replace such buoys, and to levy any rate not exceeding one penny per register ton on and in respect of all vessels which may use such buoys for the purpose of swinging, to have their compasses adjusted." And in 1868 a set of buoys, five in number (Fig. 1), were laid down near the head of Gare Loch, in from 53 ft. to 65 ft. depth of water, at low water.

Fig. 1.




Sketch showing relative positions of Buoys laid down in Gare Loch for Swinging Vessels, 1868.

The whole of the buoys are of iron, pear-shaped. The centre buoy weighs about 7 tons, is 12 ft. in extreme depth, by 9 ft. 8 in. in extreme diameter, with timber belting, 3 ft. 9 in. broad, by $4\frac{1}{4}$ in. thick, round the centre, and is moored with 80 ft. of $2\frac{5}{8}$-in. chain to a cast-iron screw 3 ft. 6 in. over the blades, sunk about

8 ft. into the sandy bottom of the loch. The four side buoys weigh about $3\frac{3}{4}$ tons each, are 10 ft. 6 in. deep by 7 ft. diameter, have no timber belting, and are each moored by a $1\frac{1}{2}$-in. chain to a cast-iron mushroom mooring 7 ft. 6 in. diameter, weighing $3\frac{1}{4}$ tons. The cost was as follows:—

| | £. | s. | d. |
|---|---|---|---|
| Buoys . . . . . | 766 | 17 | 0 |
| Chains, moorings, fixing, &c. . . . . | 387 | 17 | 10 |
| Total . . . | £1,154 | 14 | 10 |

The rate charged for the use of the buoys is $\frac{1}{2}d.$ per register ton. 172 vessels, of the aggregate tonnage of 80,664 tons, used the buoys during the year 1872, yielding a gross revenue of £168 1*s.*

## Acts of Parliament.

The first Act for the improvement of the river Clyde was obtained by the Magistrates and Council of the city of Glasgow, in the 32nd year of the reign of George the Second (1759). The Author considers the preamble cannot but be interesting, and that the history of the river would be incomplete without it:—"Whereas, the River Clyde from Dumbuck to the Bridge of Glasgow is so very shallow in several parts thereof that boats, lighters, barges, or other vessels cannot pass to and from the City of Glasgow except it be in the time of flood or high water at spring tides; and if the same was cleansed and deepened, and the navigation thereof made more commodious, by a lock or dam over the same, it would be a great advantage to the trade and manufactures of the city and parts adjacent and to the public in general." By this Act power was given to the Magistrates and City Council of Glasgow for the time being "to cleanse, scour, straighten, enlarge, and improve the said River Clyde from Dumbuck Ford to the Bridge of Glasgow, and to dig, cut, deepen the same, or any part thereof, and to cut, remove, take, and carry away all trees, roots of trees, sand or gravel beds, and all other impediments whatsoever which may any ways hinder or obstruct the said navigation; and to build, erect, and make in, over, or on the said river, or the lands adjoining to or near the same, or any of them, such and so many locks, wears, pens, dams, and cuts, trenches, and other works as to the said Magistrates and Council, and their successors in office, shall appear necessary or convenient for the promoting the said navigation, &c., &c. Provided always, that no lock or dam in, over, or upon the said River Clyde be built,

erected, or made by the authority of this Act any lower down the said river than the lowermost part of a place therein called *Merlinford;* and that no dam shall exceed the height of 7 feet." It also empowered them to charge certain duties for defraying the expenses of carrying on the said works, and certain tolls, lock and keelage duties, payment of which were, however, only to commence "from the time that the said lock or locks shall be erected and rendered passable, and not sooner."

In 1770, the second Act was obtained, to explain and amend the first Act. This Act narrates that:—"Whereas since the passing of the Act made in the 32nd year of the reign of his late majesty King George the Second, the said Magistrates and Council have caused a more accurate survey of the said River Clyde to be taken, and are now advised that by contracting the channel of the said River Clyde, and building and erecting jettees, banks, walls, works, and fences in and upon the said river, and dredging the same in proper places between the lower end of *Dumbuck Ford* and the Bridge of Glasgow, the said River Clyde may be further deepened, and the navigation thereof more effectually improved, than by any lock or dam, and so as there shall be seven feet water in every part of the said river at neap tides:

"And whereas by the said Act the levying the rates and duties thereby granted stands suspended until the lock or locks thereby authorized shall be erected and made passable, and that this suspension of the collecting the said rates and duties which by this present Act are intended to remain and continue, will greatly retard the improving of the navigation of the said river; and that it is necessary a new mode or plan for levying and collecting the rates and duties be established, and a proper consideration granted to the said Magistrates and Council and their successors, in consideration of the great labour they must be at, and of the risque their common stock must run, in improving the navigation of the said river." The Act repeals the suspension of the collection of the rates and duties, and empowers the Magistrates to demand the rates granted by the first Act, and "to make and keep the said River Clyde navigable from the lower end of *Dumbuck Ford* to the Bridge of Glasgow aforesaid, so as there may be at least seven feet water at neap tides in every part of the said river within the bounds aforesaid for ships, vessels, barges, and lighters to come and go, to and from the said City of Glasgow, and for that end to alter, direct, and make, or cause to be altered, directed, and made, the channel of the said river through any land, soil, or ground (part of the present bed of the said river) between the

lower end of Dumbuck Ford and the Bridge of Glasgow aforesaid, and to make, set up, and erect on both sides of the said river such and so many jettees, banks, walls, sluices, works, and fences for making, securing, continuing, and maintaining the channel of the said river within proper bounds, for the use of the said navigation, as to the said Magistrates and Council, and their successors in office, shall seem proper and convenient, and for that purpose to cleanse, scour, deepen, and enlarge, or straighten or confine the said river and channel thereof, or any part or parts of the same, within the limits aforesaid, and to dig or cut the soil, ground, or banks of the said river, and soil, sand, and gravel in the bed thereof, and to lay the same upon the most convenient banks of the said river, and to plant the banks on each side of the said river within the bounds aforesaid with willows, or other shrubs, for the safety or preservation of the said banks, and for preventing the same from being hurt or carried away by the said river."

The third Act was obtained in 1809; by it power was given to deepen the river "till such time as the said river is at least nine feet deep at neap tides in every part thereof between the Bridge of Glasgow and the Castle of Dumbarton," and the Lord Provost, Magistrates, and Council of the city of Glasgow for the time being, and their successors in office were constituted Trustees.

The fourth Act was obtained in 1825; by it power was given to deepen the river between the Bridge of Glasgow and Port Glasgow, "till such time as the said river is at least thirteen feet deep;" and "five other persons interested in the trade and navigation of the river and Frith of Clyde," whom the Magistrates and Council were authorised to appoint, were added to the Trustees.

The fifth Act, which was obtained in 1840, empowered among other things the making of a dock at Glasgow, and the carrying out of the deepening "until the said river and harbour throughout every part thereof shall have attained at least the depth of seventeen feet at neap tides."

This was the last Act authorising any important works connected with the river apart from the harbour.

The sixth Act, obtained in 1846, was for a wet dock, or tidal basin; then followed the Money Act of 1854, the Continuance Act of 1857, the Consolidation Act of 1858, the Tramway Act of 1864, the Graving Dock Act of 1868, and the Stobcross Dock Act of 1870.

By the Consolidation Act of 1858, the constitution of the Trust was materially altered. Previous to the passing of that Act the management of the harbour and the river was virtually in the

hands of the Magistrates and Town Council of Glasgow. By that Act, which is still in force, the number of Trustees was fixed at twenty-five, one being the Lord Provost of Glasgow, nine Town Councillors, and the remaining fifteen representatives of the shipping, mercantile, and trading interests of Glasgow, of whom two must be chosen by the Chamber of Commerce of Glasgow, two by the matriculated members of the Merchants' House of Glasgow, two by the members of the Trades' House of Glasgow, and nine by the ship-owners and ratepayers. The qualification of the Trustees to be elected by the ship-owners and ratepayers is ownership to the extent of at least 250 tons in any vessel, or vessels, registered at the port of Glasgow, or payment of rates to the extent of £25, or upwards, per annum; and of electors, ownership to the extent of at least 100 tons, or payment of £10, or upwards, of rates per annum.

As showing the charges of engineers in olden times, the Author will here quote an interesting statement prepared, in 1834, by the Trustees' Treasurer :—

"Statement of Sums paid to Engineers, for Surveys, Reports, etc., for improving the River Clyde and Harbour of Glasgow, from 1752 to 1834.

| | | £. | s. | d. |
|---|---|---|---|---|
| "1752. | John Stirling | 28 | 4 | 4 |
| 1756. | John Smeaton | 21 | 0 | 0 |
| 1758. | „ | 91 | 11 | 0 |
| 1760. | „ | 43 | 0 | 0 |
| „ | „ | 69 | 0 | 0 |
| 1769. | John Golborne | 85 | 0 | 0 |
| 1770. | James Watt | 20 | 0 | 0 |
| „ | John Golborne | 21 | 0 | 0 |
| „ | „ | 29 | 14 | 2 |
| „ | James Watt | 21 | 14 | 0 |
| 1771. | John Golborne | 105 | 0 | 0 |
| 1800. | John Rennie | 35 | 0 | 0 |
| 1802. | William Kyle, for Plan of River | 99 | 12 | 5 |
| 1803. | John Rennie | 16 | 1 | 8 |
| 1806. | Thomas Telford | 18 | 10 | 8 |
| 1808. | John Rennie | 51 | 1 | 0 |
| 1809. | „ | 93 | 4 | 9 |
| 1810. | „ | 41 | 3 | 5 |
| 1811. | „ | 37 | 7 | 0 |
| 1812. | R. Buchanan | 35 | 0 | 0 |
| 1817. | John Rennie | 7 | 7 | 0 |
| 1821. | Thomas Telford | 150 | 0 | 0 |
| 1825. | Mr. Whidbey | 260 | 0 | 0 |

| | | £. | s. | d. |
|---|---|---|---|---|
| 1826. | William Kyle, for taking soundings of the river, from Glasgow to Port Glasgow . . . . | 108 | 6 | 11 |
| 1827. | Robert Stevenson . . . . . | 11 | 11 | 0 |
| „ | Thomas Telford. . . . . | 236 | 10 | 0 |
| 1831. | Robert Stevenson . . . . . | 13 | 4 | 6 |
| 1833. | „ . . . . . | 85 | 2 | 1 |
| 1834. | Mr. Hartley (not yet rendered). | | | |

"Taken from the Books of the Trustees for Improving the River Clyde, by John Spreull, Treasurer.

"Glasgow, 8th Oct., 1834."

## Introduction of Steam Propulsion and Progress of the Shipping Trade on the River.

The first steamer built on the Clyde was the 'Comet,' constructed in 1811–12 for Henry Bell, of Helensburgh, and from his designs, by John Wood, ship-builder, Port Glasgow, and engined by John Robertson, of Glasgow, at the cost of £192. It was 40 ft., length of keel, and 12 ft., beam; its engines were 4 H.P.; its draught of water 4 ft., and it was capable of carrying 40 passengers fore and aft. It plied between Glasgow, Greenock, and Helensburgh, sailing from Glasgow the one day and returning the next. Its first voyage was on the 18th of January, 1812.

An old gentleman, seventy-seven years of age, and who has been connected with the Clyde for upwards of fifty years, informed me a short time ago that he made a voyage in the 'Comet' in 1812. He left Greenock at 10 A.M. for Glasgow, but, in consequence of a ripple of head wind, it was 2 P.M. before they got to Bowling, 10½ miles above Greenock, where all the passengers were landed and had to walk to Glasgow, owing to the want of water, the tide having ebbed. It was no uncommon occurrence for the passengers, when the little steamer was getting exhausted, to take to turning the fly-wheel to assist her.

Henry Bell, like too many pioneers, failed to profit by the successful application of steam to navigation, which has, in the short space of 60 years, so benefited the whole human race; and in his declining years he was chiefly supported by an annuity of £50, granted him by the Clyde Trustees. He died at Helensburgh in 1830, aged 63.

By 1818, passenger steamers were numerous on the river, going as far as Rothesay, Largs, and even Campbeltown. The fares were 4*s.* to Greenock, and 7*s.* to Rothesay. Then, in consequence of the shallowness of the river, they sailed from Glasgow only about the top of high water; now, they sail at fixed hours,

at all states of the tide, and the fares are 1*s.* to Greenock, and 1*s.* 6*d.* to Rothesay.

The voyager in the early days of steam navigation on the Clyde seldom accomplished the passage up or down the river without undergoing the excitement of feeling the steam-boat run upon one or more of the numerous shoals and sand banks with which the bed of the river then abounded, and, on such occasions, it was the usual practice for the captain to employ his passengers in moving rapidly from one end of the vessel to the other to aid in getting the vessel off the shoal.

Fly-boats for passengers, with sails and oars, were used before the introduction of steam-boats, a whole day being often spent on the passage between Glasgow and Greenock; and lighters, drawing not more than 4 ft. 6 in., have been known, owing to neap tides, and consequent groundings, to take six weeks to complete the passage from Greenock to Glasgow and back. Steam lighters now do the same double voyage in about as many hours.

Before the year 1818, none of the vessels in the foreign trade came farther up the river than Greenock or Port Glasgow. Their cargoes were discharged into lighters, which carried them to Glasgow. These lighters were sailed, rowed, and poled up to Renfrew, and were then towed up to the harbour by either men or horses.

At this time the largest ship belonging to either Glasgow or Greenock did not exceed 400 tons; 250 tons to 300 tons was the common size, and the largest lighter was about 60 tons.

Steam-tugs, for towing the lighters, followed soon after the introduction of passenger steamers, and in recent years steam has been extensively applied to the lighters themselves. Towing sailing vessels on the river by steam-tugs is now nearly universal. All large vessels employ tugs. Small craft are formed into trains, and each train is towed by one tug. The large fleet of trans-atlantic steamers which trade between Glasgow and America, and all the larger foreign trading steamers, are taken over the navigation by tug steamers, one at the bow and one at the stern, under the charge of duly licensed pilots.

## Ship-building.

The ship-building trade of the Clyde is now the most important in the kingdom, and a large portion of the mercantile steam navy of the world is now constructed on its banks.

In 1868, the total number of vessels built and launched on the

Clyde was 232 of 174,978 tons, including 8 war vessels of 5,384 tons.

In 1869, 240 vessels of 194,000 tons, including 3 war vessels of 9,100 tons.

In 1870, 234 vessels of 189,800 tons, including 1 war vessel of 2,640 tons.

In 1871, 231 vessels of 196,200 tons, including 6 war vessels of 3,050 tons.

In 1872, 227 vessels of 224,000 tons; no war vessels.

The great economy recently arrived at in the consumption of fuel, and the opening of the Suez Canal, have, during the last three years, led to the increasing production of screw steam-ships, and to the almost total stoppage of the building of sailing vessels.

The number of sailing vessels built on the Clyde was:—

In 1868, 108 of 79,346 tons.
„ 1869, 113 of 90,030 „
„ 1870, 83 of 42,595 „
„ 1871, 40 of 15,870 „
„ 1872, 38 of 15,100 „

At Faskine, on the banks of the Monkland Canal, 11 miles from Glasgow, the first iron vessel was built by Thomas Wilson, and was launched on the 20th May, 1818. It was named the 'Vulcan,' and is still plying on the Clyde, engaged conveying minerals from the Forth and Clyde Canal to ports on the river.

### Dredging, &c.

A variety of appliances for dredging have been employed in the deepening and widening of the Clyde.

Where the sand banks in the river were bare at low water, common land ploughs, wrought by horses, were called into use, the object being to break up the banks, so that the current might carry the sand away.

Another description of plough was much used. It consisted of a front plate of iron about 3 ft. 6 in. long by 16 in. deep, with two timber sides about 5 ft. long, 16 in. deep at the front, where they were firmly fixed to the iron plate, and tapered to about 10 in. at the back, where they were kept parallel with the front by an iron bar 'kneed down' at the ends and fastened to the sides. When this plough was employed for the removal of gravel banks, the front plate was armed with four iron prongs, which projected about 8 in. or 9 in. below the bottom edge of the plate, and it was then called a 'porcupine plough.' A modification of this description of

plough was also used. It was smaller in size, with iron sides, and had prongs projecting beyond both edges of the front plate so as to be reversible. It was so hung that the one side took a deeper hold than the other. The ploughs were fitted up with sling-chains at each end, and were wrought in pairs by hand capstans, two of which were placed on the river bank and two on a punt moored in the river, on the opposite side of the bank to be removed. One set of men on shore hauled the ploughs alternately through the bank towards them with their load of sand or gravel, which was removed at low water on to the adjoining land, and a set of men on the punt drew the empty ploughs alternately back for a fresh hold.

Harrowing, also, was had recourse to. Taking advantage of freshes in the river, a harrow was attached by tackle to the stern of a tug steamer, which set off with the tide, tearing up the bottom as far as requisite. The harrow was then lifted, and the tug steamed back against the tide, and, again dropping the harrow, repeated the operation.

Dredgers, with small buckets on a ladder, wrought by hand and by horses, followed the plough and harrow, and in 1824, the first steam dredger was started. It dredged only to 10 ft. 6 in.; two years afterwards it was altered to dredge to 14 ft.; now several of the dredgers employed can work to nearly 30 ft.

The cost of dredging, of course, varies much according to the character of the material to be lifted, and to the power of the dredger employed and the capacity of its buckets. The material to be dredged ranges from silt and sewage deposit to the hardest of gravel and boulders, completely concreted together. Where good lifting sand was being dredged, one of the two most powerful of the Trustees' dredgers lifted, on each of five consecutive days in the month of August last, 2,240 cubic yards, or about 2,800 tons, the engine working 9 hours the first day, $9\frac{3}{4}$ hours the second, third, and fifth days, and $9\frac{1}{4}$ hours the fourth day, the average strokes of the engine being 33 per minute, and the average depth of water that the points of the buckets were working at, 20 ft.

Full details with reference to the dredging operations on the Clyde are given in the Appendix.[1] It may here be noted that last year the engine of No. 5 dredger worked $2{,}297\frac{1}{2}$ hours, and lifted 48,618 cubic yards, or 21·16 cubic yards per engine hour, of hard till, gravel, and sand, at the cost of 8·97*d.* per cubic yard; No. 6, 2,426 hours, lifted 276,960 cubic yards, or 114·16 cubic

[1] *Vide* Appendix, IV.–XIII., pp. 156–169.

yards per engine hour, of silt, clay, and sand, at the cost of 3·36*d.* per cubic yard; No. 7, 2,242 hours, lifted 37,736 cubic yards, or 16·83 cubic yards per engine hour, of very hard gravel, boulders, and clay, concreted together, at the cost of 13·46*d.* per cubic yard; No. 8, 2,386¼ hours, lifted 366,080 cubic yards, or 153·41 cubic yards per engine hour, of silt, sand, till, and gravel, at the cost of 2·81*d.* per cubic yard; and No. 9, 2,045 hours, lifted 262,960 cubic yards, or 128·58 cubic yards per engine hour, of till, gravel, clay, sand, and mud, at the cost of 2·95*d.* per cubic yard.

Dredging goes on in the Clyde all the year round. 2,279 were the average engine hours wrought by each dredger last year, and 2,402 hours the year before; 2,400 hours may be taken as the actual working time of the dredgers on the river per annum.

'Repairs' forms a heavy item in the working expenses of a dredger. About an hour each day on the average is consumed in replacing pins, links, and buckets; time is necessarily taken up by frequent shiftings from place to place, and nearly every year each dredger is laid up for several weeks to undergo a thorough overhaul. Fogs cause some loss of time every winter.

The dredgers are used not merely for the deepening, they are likewise employed in the widening of the river. When a bank has to be cut away, the dredger is worked as close to it as can with safety be permitted, so as to undermine and lift the material, which is thus removed at much less cost than by ordinary excavation.

Where the buckets of the dredgers cannot get close enough to quay walls, what is technically called 'spooning' is employed to withdraw the material from the front of the walls sufficiently far out to enable the dredgers to lift it. The 'spoons' used are large pronged spades with straight handles 52 ft. long. They are wrought in pairs by hand crab-winches, two on the quay, and two on a punt moored in the river. One man holds the handle of each at the edge of the quay. One set of three men on the quay, and one set of three men on the punt, work the spoons alternately from the face outward with a load, and backward again for a fresh spoonful.

### Diving-Bells and Blasting Operations.

Stones weighing as much as 17½ cwts. are occasionally lifted by the dredgers, but diving-bells are employed for the lifting of boulders, some of which weigh upwards of 6 tons. Last year only one of the bells was continuously at work, and, by means of it, 656 tons of boulders were lifted from the bed of the river.

The most important work the diving-bells have, however, been engaged at during the last twenty years has been the removal of a remarkable bed or dike of Whinstone or trap rock from the bed of the river at Elderslie, about 4 miles below Glasgow, which has formed and still forms a serious impediment to the deepening of the river. As the rock did not crop out either in the bed of the river or on either of its banks, its existence was unknown until the year 1854, when one of the first line of steamers between Glasgow and New York, drawing the maximum draught of water that the navigation was capable of accommodating in those days, while going down the river, grounded on the rock, knocked a hole in its bottom, and had to be discharged and repaired at a cost of about £2,000. It was at first thought that it might be a large boulder, but borings showed that it extended over an area of the bed of the river, about 900 ft. in length by about 300 ft. in breadth. It was then proposed to cut a temporary channel for the river at the place, and to quarry out the rock to the required depth and width. This proposal was not carried out, and blasting with gunpowder under water was adopted. A movable wrought-iron stage, 20 ft. long by 15 ft. broad on the top, was constructed, with legs resting on the bed of the river. These legs were movable, to suit the varying level of the bottom. From the floor of the stage, which stood about 3 ft. above high-water level, a series of holes 3 in. diameter were drilled, by manual labour, into the rock; these were charged with gunpowder contained in tin canisters. The holes were then run up with Roman cement. The charges were fired in groups, by a galvanic battery, from the deck of the diving-bell barge, and the shattered rock was removed by means of the bells. Thus, at a cost of upwards of £16,000, the northern half of the area has been lowered so as to give a channel 14 ft. deep at low water, the other half having an available depth of 8 ft. Much remains to be accomplished before 20 ft. at low water can be obtained, but the Author hopes, by the application of steam drilling and dynamite, at least to keep pace with the gradual deepening of the navigation, above and below this rock.

### Deposit of Dredged Material.

Previously to the year 1862, the whole of the dredged material was deposited on land at the cost, in 1861, of 10·37*d.* per cubic yard, for depositing alone, exclusive of interest on cost of, or allowance for depreciation on, the plant employed. Many acres of alveus thus reclaimed became the property of the riparian proprietors, who are now asking from £1,200 to £1,400 per acre for it.

The difficulty of making reasonable arrangements with landowners for permission to deposit dredgings on the alveus, and on the low land adjoining the river, and the great cost of doing so—when the landowners, for valuable considerations, in the shape of rent, or the acquisition by them of the land reclaimed, gave permission—led the Trustees, in 1862, to adopt steam hopper barges, for the purpose of conveying the dredgings to sea. The result for 1870–71 was, that the cost of conveying 673,240 cubic yards of dredgings to, and depositing them in Loch Long, 27 miles from Glasgow (B B, Plate 19), was £15,323 8*s.* 2*d.*, or 5·46*d.* per cubic yard—£5,151 of that sum, or 1·84*d.* per cubic yard, being 10 per cent. on value of barges, for interest and depreciation; while for a particular quantity of 122,664 cubic yards deposited on land, the cost was 16·40*d.* per cubic yard—3·52*d.* of that rate being in like manner 10 per cent. on value of punts, for interest and depreciation. The cost of depositing by barges for the year 1871–72 was 5·13*d.* per cubic yard. Last year 992,354 cubic yards, or about 1,240,000 tons, were dredged from the harbour and river, of which 299,446 cubic yards were considered deposit from the higher reaches of the river and its tributaries, and from the city sewers; and 692,908 cubic yards new material from the deepening and widening of the harbour and river; 906,000 cubic yards were carried out to sea, and 86,304 cubic yards deposited on land. But for the use of steam hopper barges, it would have been well nigh impossible to have disposed of such a large quantity of dredged material.

During the last 28 years 14,609,454 cubic yards, or upwards of 18,000,000 tons, have been dredged from the river by the Clyde Trustees; and the total expenditure for dredging and depositing alone, since the year 1770, has been upwards of £500,000.

The dredging plant of the Clyde Trust consists of:—

6 steam dredgers,
14 steam hopper barges,
1 steam-tug,
3 diving-bells,
270 punts, and numerous small boats;

one steam dredger and four steam hopper barges having been added to the dredging plant during 1871.

Its value is £140,000. For its repair the Trustees, in 1867, erected on the side of the river at Dalmuir, 8 miles below Glasgow, an extensive range of works, at a cost of £25,000. These works

include a patent slip, capable of taking on the largest dredger. They give employment to 140 hands. In the smith's department three steam-hammers are constantly employed, forging the heavy links, pins, &c., required for the various dredgers.

The Author believes that the following details as regards the dredgers and barges may be useful:—

No. 9. Dredger.

| General Dimensions:— | Ft. | In. |
|---|---|---|
| Extreme length | 161 | 0 |
| Breadth moulded | 29 | 0 |
| Depth at sides amidships | 10 | 0 |
| Rise of deck at centre | 0 | 10 |
| Sheer of deck | 2 | 3 |

One bucket ladder, 89 ft. 6 in. between centres.
Size of buckets, 3 ft. 3 in. × 2 ft. 5 in. × 1 ft. 11 in.
Mean working draught, 6 ft. to 7 ft.

Engines.—Horizontal, condensing, 2 cylinders with link motion, governor, and all recent improvements, say 75 H.P.

| | Ft. | In. |
|---|---|---|
| Diameter of cylinders | 2 | 3 |
| Length of stroke | 3 | 0 |

Average strokes per minute, 33.

Boiler.—Horizontal, tubular, with 3 furnaces, each 3 ft. 1½ in. wide.

| | Ft. | In. |
|---|---|---|
| Length at bottom | 9 | 4 |
| Width | 11 | 4 |
| Height | 13 | 10 |

Working pressure of steam 10 lbs. to 15 lbs. per square inch.

Consumption of Coals, &c.:—

| | |
|---|---|
| Coals, per day of 10 hours | 50 cwts. to 60 cwts. |
| Tallow „ „ | about 1 lb. |
| Oil (lard) „ „ | 13½ gills. |
| Waste „ „ | 1½ lb. |

Nos. 11, 12, 13, and 14. Steam Hopper Barges.

| General Dimensions:— | Ft. | In. |
|---|---|---|
| Length of keel and fore rake | 145 | 0 |
| Breadth, moulded | 25 | 0 |
| Depth, ditto | 11 | 9 |
| Length of hopper | 56 | 0 |
| Breadth of ditto at deck | 19 | 6 |
| Ditto, ditto bottom | 8 | 6 |
| Height of coamings at sides of hopper | 1 | 4 |

Capacity of hopper, about 320 cubic yards, or 400 tons.
Engines, &c.—Direct acting, condensing, 2 cylinders, each 24 in. diameter, and 24 in. stroke. Expansion valves, link motion, &c., say 40 H.P.
Propeller, 3 bladed, 8 ft. diameter, pitch about 16 ft.
Boiler.—Cylindrical, 11 ft. diameter, and 9 ft. 6 in. long, tubular, fitted with superheater, 2 furnaces, working pressure 30 lbs. per square inch.
Draught, Speed, &c.—Loaded—with sand—9 ft. 6 in. forward, and 11 ft. 6 in. aft. Light—boiler full, and 20 tons to 30 tons of coal in bunkers—4 ft. forward, and 8 ft. 2 in. aft.
Speed, 8 miles to 9 miles per hour.
Strokes of engine, average 70 per minute.
Steam pressure, 25 lbs.; vacuum, 24.
Consumption of Coals, &c.:—

| | | | |
|---|---|---|---|
| Coals, per | day of 10 hours | . . . . . | 70 cwts. |
| Tallow | „ | „ . . . . . | 5 lbs. |
| Oil | „ | „ . . . . . | 20 gills. |
| Waste | „ | „ . . . . . | 2 lbs. |

## Dykes and Banks.

From Glasgow to below the mouth of the river Cart, on the north side, and to near Erskine Ferry, on the south side, the river dykes have all disappeared; and for that length the river flows through land now above the level of high water, much of which has been raised to that level by deposit from the river. The slopes of the banks are generally 1½ horizontal to 1 vertical, and are covered with Whinstone rubble.

Until four years ago, when the Author entered on the charge of the Trustees' works, the stone was hand-pitched, at a cost, for labour alone, of 1*s.* 2*d.* per square yard; since then, pitching has been discontinued, and the stones are left as laid on. It is found that the slopes stand better thus than pitched; and break the wash of the steamers' waves more effectually. Where the slopes have only to be temporarily protected, a coating of stone, not exceeding 12 in. average thickness, will, with a little attention, effectually preserve them for months. Last year 7,300 tons of stones were used. The only training-dykes now in existence on the river are a length of 1,800 yards on the north side, above Dalmuir; and 5,700 yards on the south side, from opposite Bowling to Dumbarton Castle.

## Expenditure and Debt.

The total expenditure of the Clyde Trustees, since 1770, amounts to £5,594,981 14*s.* 8*d.*, of which £1,390,947 18*s.* is for interest on borrowed money, £724,453 8*s.* 3*d.* for land for the enlargement of

the harbour, and £164,838 for land for widening the river below the harbour. The whole of the expenditure has been paid out of the rates and by money borrowed on the security of the rates.[1]

The total debt of the Trust, as at 30th of June, 1872, amounted to £2,151,557 8*s.* 3*d.*

The Paper is illustrated by a series of drawings and diagrams, from which Plates 19, 20, 21, 22, and 23 have been compiled.

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[1] *Vide* also Appendix, XIV. and XV., pp. 170 and 171.

THE RIVER CLYDE.
1872.
REFERENCES.
A. Positions of Bueys for swinging Vessels in Gare Loch.
B. B. Deposit of dredgings in Loch Long
C. C. Limit of the Jurisdiction of the Trustees of the Clyde Navigation.
Garelochhead
Bueys for swinging Vessels to adjust adjusting compasses.
GARE LOCH
LOCH LONG
ROW
HELENSBURGH
ROSNEATH
Rosneath House.
Rosneath Point
Cove
Kilcreggan
Ardentinny
Blairmore
Strone Point
Kilmun
HOLY LOCH
Sandbank
Kirn
FIRTH OF CLYDE
Ardmore Head
CARDROSS
NORTH BRITISH RAILWAY
DUMBARTON
Dumbarton Castle
Leven
Levan Castle
BOWLING
FORTH & CLYDE CANAL
OLD KILPATRICK
Erskine House
Erskine Ferry
Kilbowie
Duntocher
Clydebank
Renfrew Ferry
Govan
Partick
Whiteinch
Scotstoun
Yoker
Renfrew
Paisley
Elderslie
Johnstone
Port Glasgow
Greenock
Gourock
Inverkip
Wemyss Bay
Largs
Millport
Cumbrae
Ardrossan
Saltcoats
Irvine
Troon
Ayr
Girvan
Stranraer
Portpatrick
Whithorn
Isle of Whithorn
Wigtown
Newton Stewart
Glenluce
Port Logan
Drummore
Mull of Galloway
Portpatrick
Donaghadee
Belfast
Carrickfergus
Larne
Portaferry
Strangford
Newcastle
Kilkeel
Warrenpoint
Rostrevor
Newry
Kilkeel
Carlingford
Dundalk
Greenock Bank
Cockle Bank
Limit of the Clyde Trustees Jurisdiction
Caledonian Railway
Glasgow & South Western Railway
Fort Matilda
Scale of Statute Miles
Miles 0 1 2 3 4 5 Miles

# THE RIVER CLYDE.

1872.

REFERENCES.

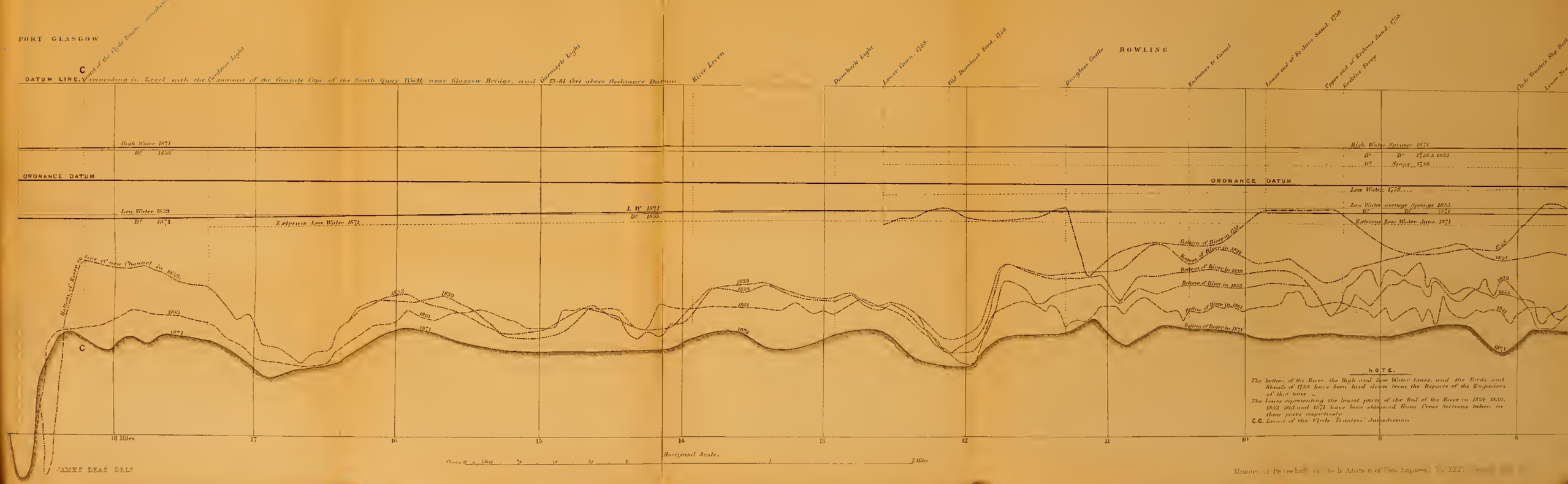
A. Positions of Buoys for swinging Vessels in Gare Loch.
B. B. Deposit of dredgings in Loch Long
C. C. Limit of the Jurisdiction of the Trustees of the Clyde Navigation.

Minutes of Proceedings of The Institution of Civil Engineers Vol. XXXV. Session 1872-73

ZETTLER LITH. MUNICH

# THE RIVER CLYDE.

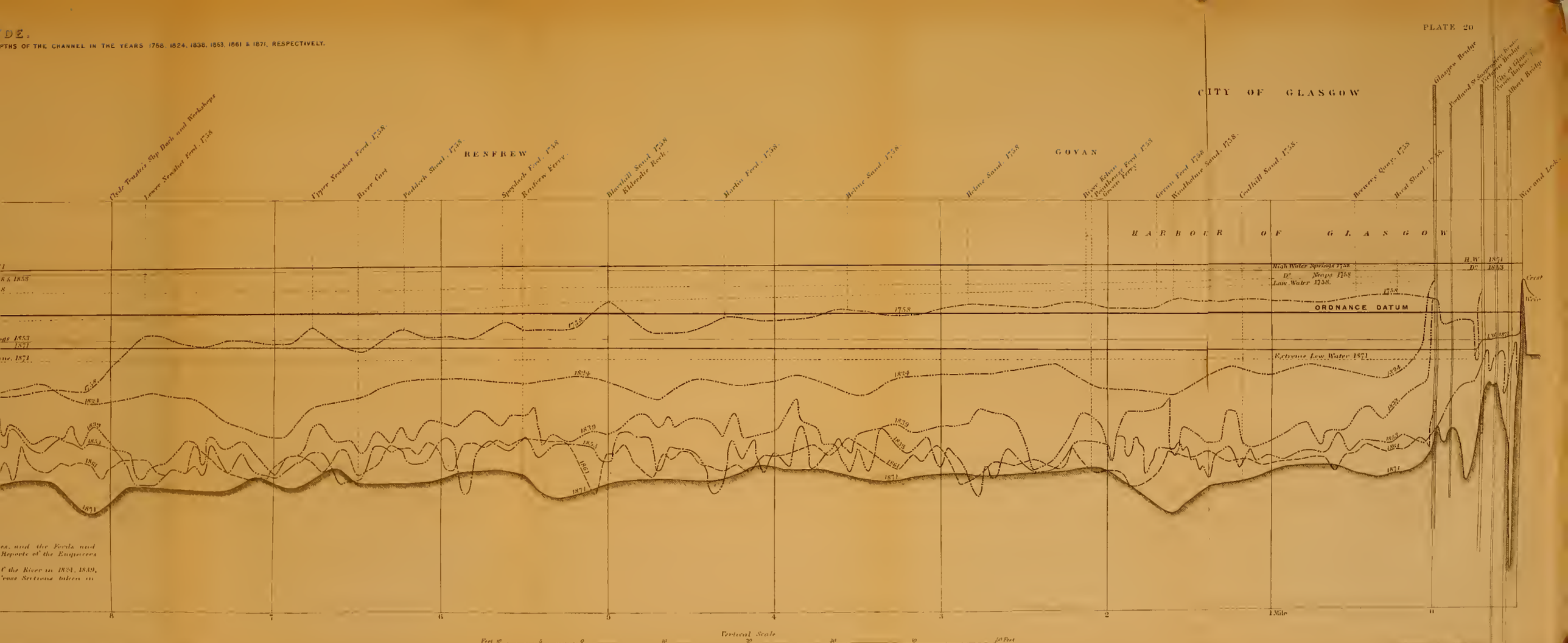
LONGITUDINAL SECTION OF THE RIVER FROM GLASGOW TO PORT GLASGOW, SHOWING THE GREATEST DEPTHS OF THE CHANNEL IN THE YEARS 1758,




JAMES DEAS DELT

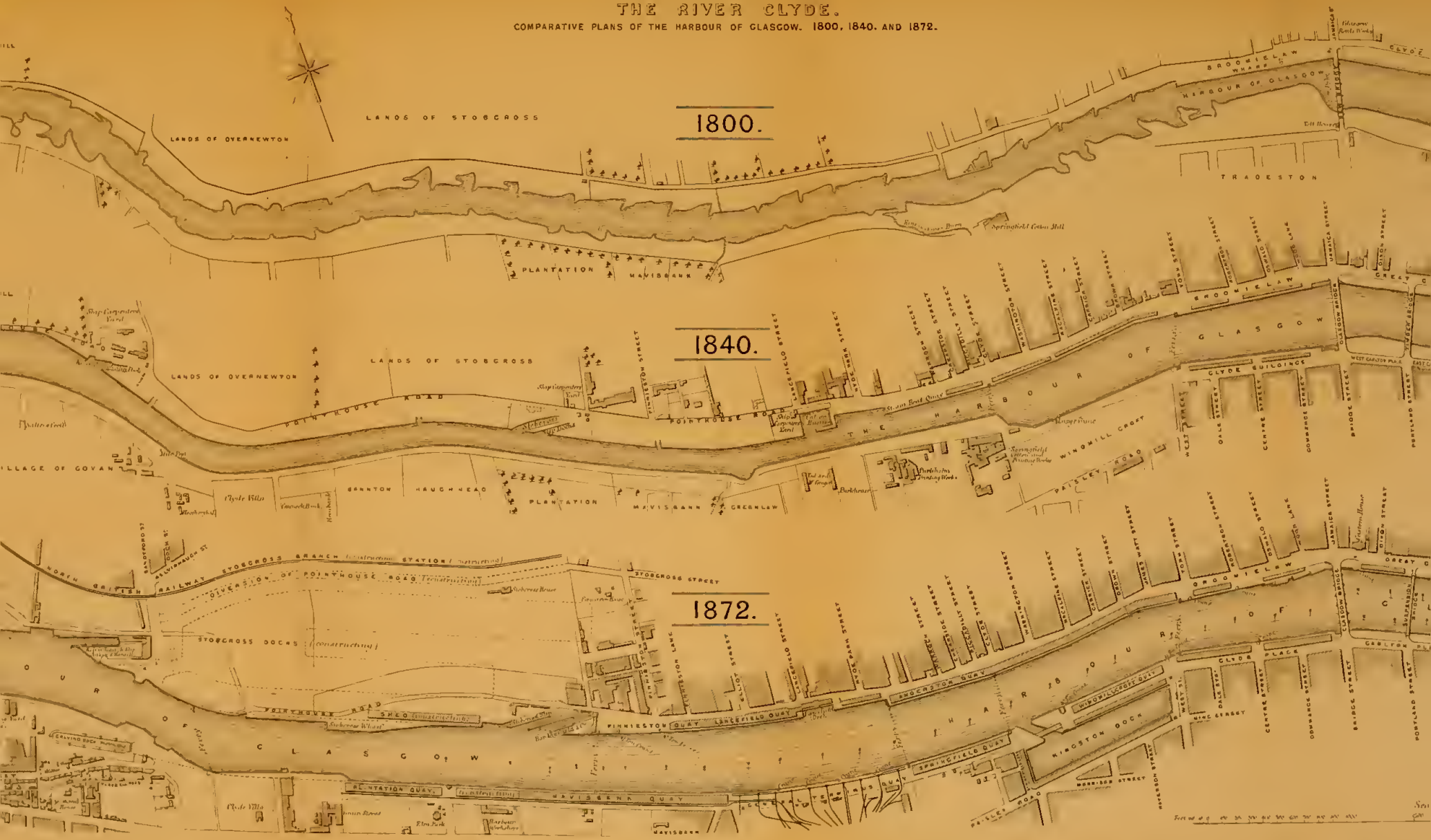
DE.

PTHS OF THE CHANNEL IN THE YEARS 1758, 1824, 1838, 1853, 1861 & 1871, RESPECTIVELY.



# THE RIVER CLYDE.

COMPARATIVE PLANS OF THE HARBOUR OF GLASGOW. 1800, 1840, AND 1872.



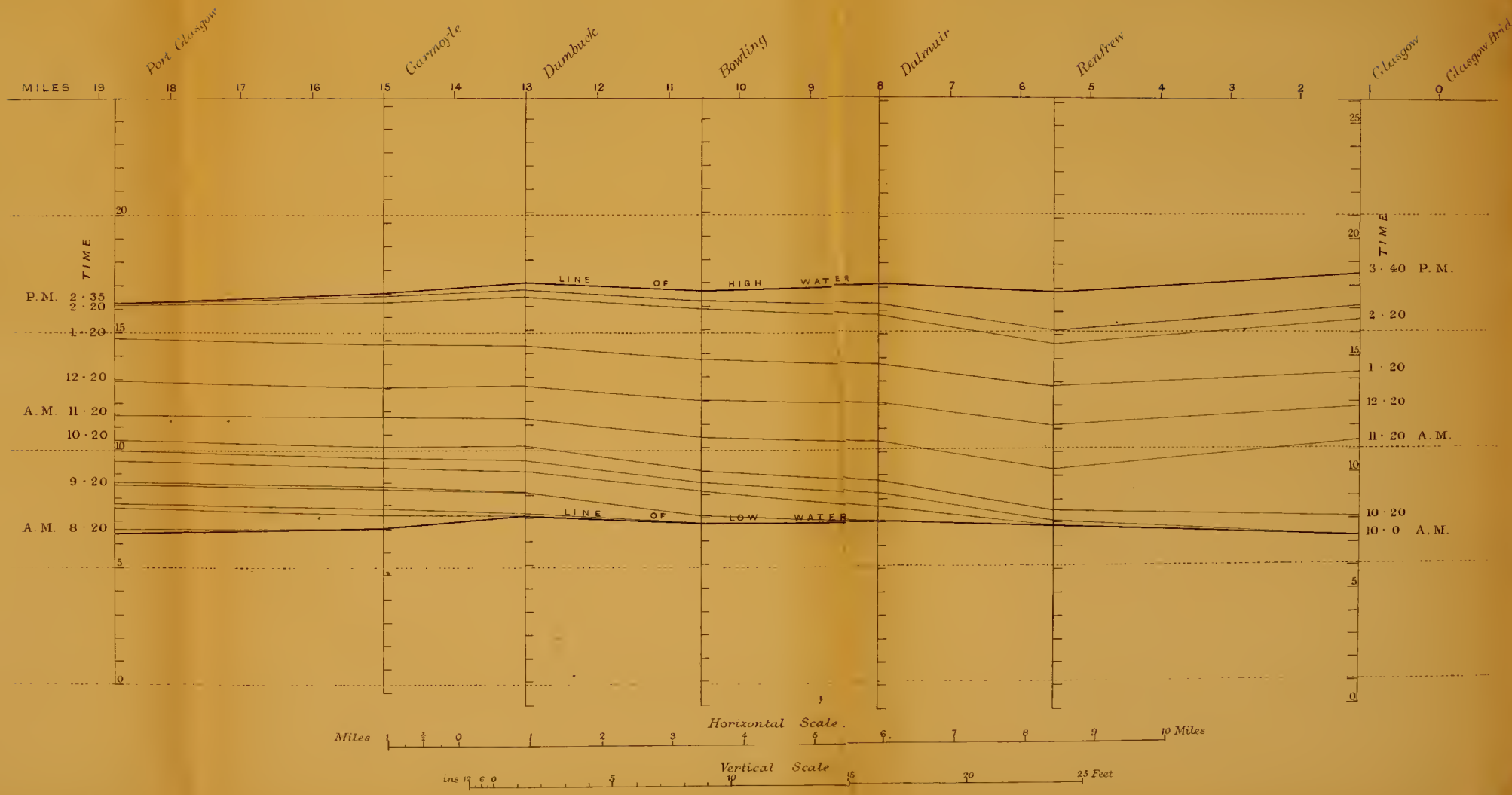

Minutes of Proceedings of The Institution of Civil Engineers Vol XXXV, Session 1872-73

# THE RIVER CLYDE.



FLOW OF A SPRING TIDE, 11th APRIL 1872, BETWEEN GLASGOW AND PORT GLASGOW.

*Diagram constructed from Table I.*




JAMES DEAN DELT

Minutes of Proceedings of The Institution of Civil Engineers Vol XXXV. Session 1872-73

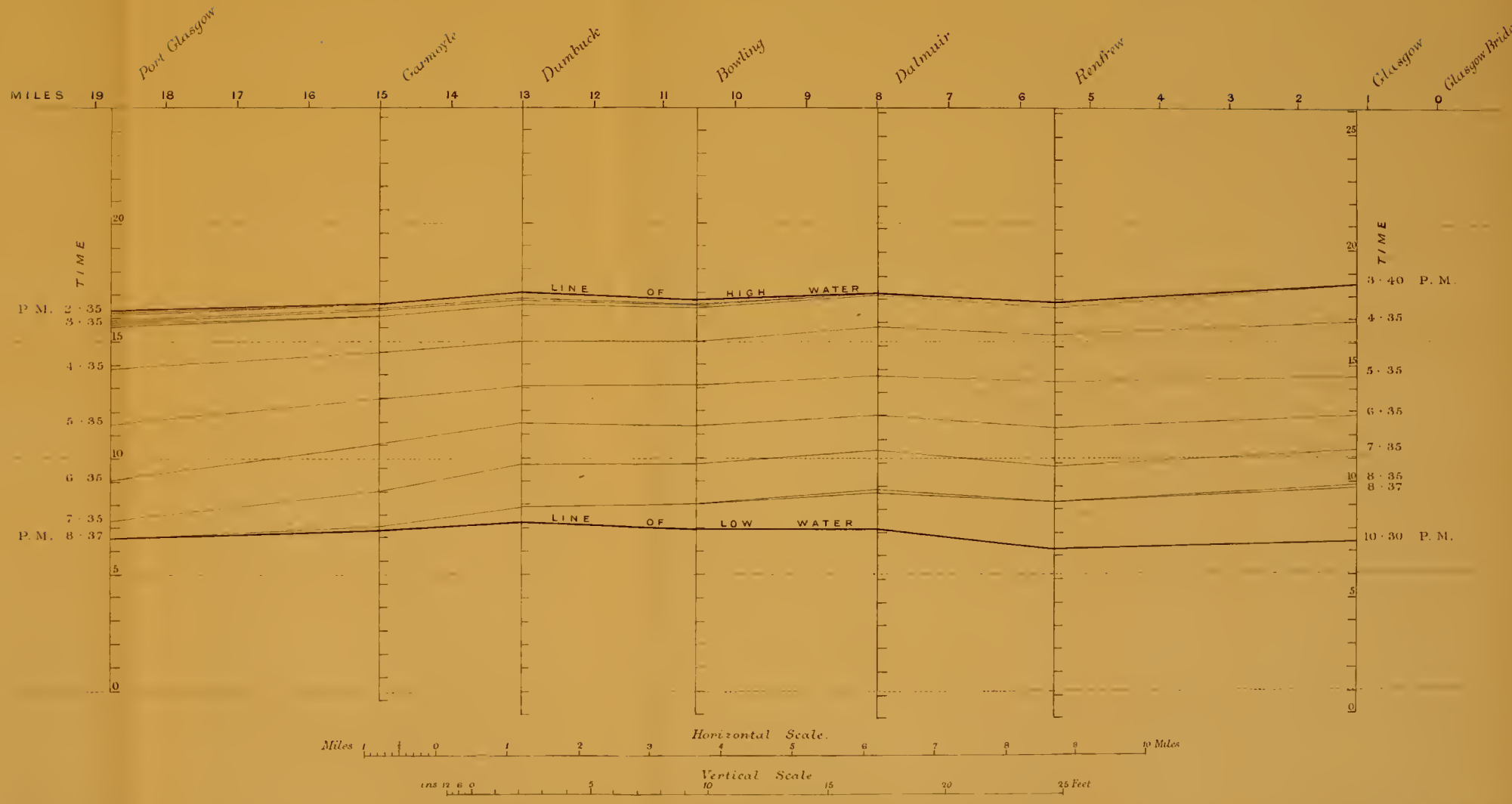
KELL, BROS LITH LONDON

# THE RIVER CLYDE.



EBB OF A SPRING TIDE, 11th APRIL 1872, BETWEEN GLASGOW AND PORT GLASGOW.

*Diagram, constructed from Table I.*



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[1] *Vide* also Plates 22 and 23.

## I.—Spring Tide observed on the 11th of April, 1872.[1]

Flowing Tide.—Weather, fair. Light breeze, generally from S.W. to W. No fresh in river.

*To face page* 154.

| Station. | Distance from Glasgow Bridge in Miles and Furlongs. | Zero of Tide-Gauge below Datum Line. | Low Water, Forenoon. Time. | Low Water, Forenoon. Reading on Gauge. | High Water, Afternoon. Time. | High Water, Afternoon. Reading on Gauge. | Rise. | Time. | H. W. Later. | L. W. Later. | Time A.M. 8·20 Reading on Gauge. | 8·27 | 8·52 | 9·00 | 9·20 | 9·22 | 9·45 | 10·00 | 10·20 | 11·20 | P.M. 12·20 | 1·20 | 2·20 | 2·35 | 2·55 | 3·00 | 3·02 | 3·25 | 3·30 | 3·40 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m. f. | ft. | h. m. | ft. in. | h. m. | ft. in. | ft. in. | h. m. | h. m. | h. m. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. |
| Port Glasgow . . | 18·5½ | 25·00 | 8·20 | 6·7 | 2·35 | 16·3 | 9·8 | 6·15 | 0·00 | 0 00 | 6·7 L.W. | 6·8 | 7·7 | 7·9 | 8·7 | 8·8 | 9 7 | 10·0 | 10·5 | 11·6 | 12·11 | 14 10 | 16·2 | 16 3 H.W. | | | | | |
| Garmoyle Light. . | 15·0 | 25·36 | 8·27 | 7·0 | 2·55 | 17·0 | 10·0 | 6·28 | 0·20 | 0·03 | | 7·0 L.W. | 7·7 | 7·10 | 8·9 | 8·10 | 9·8 | 10·0 | 10·6 | 11·9 | 13·0 | 14·10 | 16·8 | 16·11 | 17·0 H.W. | | | | |
| Dumbuck Light . | 13·0 | 25·91 | 8·52 | 8·0 | 3·00 | 18·0 | 9·11 | 6·08 | 0·25 | 0·32 | | | 8·0 L.W. | 8·2 | 9·2 | 9·2 | 10·1 | 10·5 | 11·1 | 12·3 | 13·8 | 15·4 | 17·5 | 17·9 | 18·0 | 18·0 H.W. | | | |
| Bowling Harbour . | 10·4½ | 25·92 | 9·00 | 7·9 | 3·02 | 17·8 | 9·11 | 6·02 | 0·27 | 0·40 | | | | 7·9 L.W. | 8·0 | 8·1 | 9·1 | 9·6 | 10·0 | 11·5 | 13·0 | 14·9 | 16·11 | 17·3 | 17·8 | 17·8 H.W. | 17·8 H.W. | | |
| Dalmuir Works . . | 8·0 | 26·14 | 9·22 | 8·1 | 3·25 | 18·2 | 10·1 | 6·03 | 0·50 | 1·02 | | | | | | 8·1 L.W. | 8·8 | 9·3 | 9·10 | 11·6 | 13·2 | 14·9 | 16·10 | 17·4 | 17·11 | 18·0 | 18 0 | 18·2 H.W. | | |
| Renfrew Ferry . . | 5·4 | 26·15 | 9·45 | 7·10 | 3·30 | 17·10 | 10·0 | 5·45 | 0·55 | 1·25 | | | | | | | 7·10 L.W. | 8·1 | 8·7 | 10·4 | 12·2 | 13·10 | 15·8 | 16·2 | 16·10 | 17·0 | 17·0 | 17·10 H.W. | 17·10 H.W. | |
| Glasgow Lower Harbour . . . . | 1·1½ | 26·07 | 10·00 | 7·4 | 3·40 | 18·6 | 11·2 | 5·40 | 1·05 | 1·40 | | | | | | | | 7·4 L.W. | 8·1 | 11·4 | 12·10 | 14·3 | 16·7 | 17·2 | 17·9 | 17·10 | 17·11 | 18·4 | 18·5 | 18·6 H.W. |

Ebbing Tide.—Weather, fair. Light breeze to strong breeze in lower reaches, generally S.S.W., and light breeze in upper reaches, generally S.W. No fresh in river.

| Station. | Distance from Glasgow Bridge in Miles and Furlongs. | Zero of Tide-Gauge below Datum Line. | High Water, Afternoon. Time. | High Water, Afternoon. Reading on Gauge. | Low Water, Afternoon. Time. | Low Water, Afternoon. Reading on Gauge. | Fall. | Time. | H. W. Later. | L. W. Later. | Time, P.M. 2·35 Reading on Gauge. | 2·55 | 3·00 | 3·02 | 3·25 | 3·30 | 3·35 | 3·40 | 4·35 | 5·35 | 6·35 | 7·35 | 8·35 | 8·37 | 8·57 | 9·10 | 0·35 | 9·55 | 10·15 | 10·30 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m. f. | ft. | h. m. | ft. in. | h. m. | ft. in. | ft. in. | h. m. | h. m. | h. m. | ft. in. | ft. in | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. |
| Port Glasgow . . | 18·5½ | 25·00 | 2·35 | 16·3 | 8·37 | 6·6 | 9·9 | 6·02 | 0·00 | 0 00 | 16·3 H.W. | 16·2 | 16·1 | 16·1 | 15·10 | 15·9 | 15·8 | 15·7 | 13·9 | 11·5 | 9·1 | 7·4 | 6·6 | 6·6 L.W. | | | | | |
| Garmoyle Light. . | 15·0 | 25·36 | 2 55 | 17·0 | 8·57 | 7·3 | 9·9 | 6·2 | 0·20 | 0·20 | | 17·0 H.W. | 17·0 | 17·0 | 16·9 | 16·8 | 16·6 | 16·5 | 14·11 | 12·11 | 11·0 | 9·0 | 7·5 | 7·5 | 7·3 L.W. | | | | |
| Dumbuck Light . | 13·0 | 25·91 | 3·00 | 18·0 | 9·10 | 8·3 | 9·9 | 6·10 | 0·25 | 0·33 | | | 18·0 H.W. | 18·0 | 17·8 | 17·7 | 17·6 | 17·5 | 15·11 | 14·1 | 12·5 | 10·8 | 8·10 | 8·10 | 8 5 | 8·3 L.W. | | | |
| Bowling Harbour . | 10·4½ | 25 92 | 3·02 | 17·8 | 9·35 | 7·11 | 9·9 | 6·33 | 0·27 | 0·53 | | | | 17·8 H.W. | 17·8 | 17·5 | 17·4 | 17·3 | 16·0 | 14·1 | 12·4 | 10·8 | 9·0 | 9·0 | 8·6 | 8·2 | 7·11 L.W. | | | |
| Dalmuir Works . . | 8·0 | 26·14 | 3·25 | 18·2 | 9·55 | 8·2 | 10·0 | 6·30 | 0·50 | 1·18 | | | | | 18·2 H.W. | 18·2 | 18·2 | 18·1 | 16·9 | 14·8 | 13·0 | 11·6 | 9·10 | 9·9 | 9·3 | 9·0 | 8·5 | 8·2 L.W. | | |
| Renfrew Ferry . . | 5·4 | 26·15 | 3·30 | 17·10 | 10·15 | 7·3 | 10·7 | 6·45 | 0·55 | 1·38 | | | | | | 17·10 H.W. | 17·10 | 17·8 | 16·5 | 14·5 | 12·5 | 10·10 | 9·3 | 9·3 | 8·10 | 8·5 | 7·10 | 7·6 | 7·3 L.W. | |
| Glasgow Lower Harbour . . . . | 1·1½ | 26·07 | 3·40 | 18·6 | 10·30 | 7·5 | 11·1 | 6·50 | 1·05 | 1·53 | | | | | | | | 18·6 H.W. | 16·10 | 14·6 | 12·10 | 11·4 | 9·10 | 9·9 | 9·3 | 8·11 | 8·4 | 7·10 | 7·6 | 7·5 L.W. |

Note.—The levels of the zeros of the tide-gauges are given below the datum line, which corresponds with 13·81 ft. above Ordnance datum.

[1] *Vide* also Plates 22 and 23.

II.—Graving Docks on the Clyde, 1872.

| Situation. | Public or Private. | Length of Floor. | Width of Entrance. | Depth on Cill at High Water, Ordinary Spring Tides. | Depth on Cill at High Water, Ordinary Neap Tides. | Depth on Cill at Low Water. | Remarks. |
|---|---|---|---|---|---|---|---|
| | | ft. in. | ft. in. | ft. in. | ft. in. | ft. in. | |
| Glasgow . . | Public | 560·0 | 72·0 | 22·0 | 20·0 | 12·6 | Constructing. |
| Ditto . . . | Private | 500·0 | 56·0 | 18·0 | 16·0 | 10·0 | |
| Dumbarton . . | Ditto . | 300·0 | 41·0 | 13·0 | 10·0 | 5·0 | |
| Port Glasgow . | Public | 310·0 | 45·0 | 16·0 | 14·0 | 6·0 | When altered. |
| Greenock . . | Ditto . | 500·0 | 60·0 | 20·0 | 18·0 | 7·0 | Constructing. |
| Ditto . . . | Ditto . | 350·0 | 38·0 | 11·8 | 9·8 | 1·8 | |
| Ditto . . . | Private | 295·0 | 49·0 | 14·3 | .. | .. | |
| Ditto . . . | Ditto . | 285·0 | 36·0 | 14·9 | .. | .. | |
| Ditto . . . | Public. | 220·0 | 33·6 | 9·9 | 7·9 | .. | |
| Ardrossan . . | Private | 210·0 | 40·0 | 14·9 | 13·3 | 5·0 | |
| Troon . . . | Ditto . | 284·0 | 37·6 | 11·0 | .. | .. | |
| Ditto . . . | Ditto . | 200·0 | 24·0 | 7·0 | .. | .. | |

## III.—Statistical Table.

| Date. | Length of Quays. | Area of Harbour. | Depth of Water in Harbour at High Water. | Vessels Arrived. | | | | Goods, Inward and Outward. | | Total Revenue of Clyde Trust. | Total Receipts per Lineal Yard of Quay Wall. | Customs' Revenue Collected at Glasgow. | Population of City of Glasgow. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Maximum Draught | Total Registered Tonnage. | Registered Tonnage worked per Lineal Yard of Quay Wall. | Registered Tonnage worked per Acre of Water Space. | Total Tonnage. | Tonnage worked per Lineal Yard of Quay Wall. | | | | |
| | yds. | acres. | ft. in. | ft. in. | tons. | tons. | tons. | tons. | tons. | £. s. d. | £. s. d. | £. s. d. | |
| 1801 | 382 | 4 | .. | .. | .. .. | .. .. | .. .. | .. .. | .. | 3,400 10 9 | 8 18 0 | 427 17 $7\frac{3}{4}$ | 77,385 |
| 1811 | 697 | 7 | .. | .. | .. .. | .. .. | .. .. | .. .. | .. | 4,755 3 8 | 6 16 5 | 3,124 2 $4\frac{1}{4}$ | 100,749 |
| 1821 | 697 | 7 | .. | .. | .. .. | .. .. | .. .. | .. .. | .. | 8,070 2 2 | 11 11 7 | 16,147 17 7 | 147,043 |
| 1831 | 1,543 | 14 | 14·6 | 14·0 | 732,327 | 474 | 52,309 | .. .. | .. | 18,932 0 7 | 12 5 5 | 68,741 5 9 | 202,426 |
| 1841 | 1,973 | 23 | 18·6 | 17·0 | 1,142,373 | 579 | 49,668 | .. .. | .. | 49,665 15 7 | 25 3 5 | 526,100 0 11 | 255,650 |
| 1851 | 3,591 | 51 | 20·0 | 18·0 | 1,446,606 | 403 | 28,365 | 1,023,216 | 285 | 68,875 4 9 | 19 3 7 | 675,044 15 10 | 329,096 |
| 1861 | 4,376 | 70 | 22·0 | 20·0 | 1,504,220 | 343 | 21,489 | 1,366,327 | 312 | 105,768 11 0 | 24 3 5 | 924,445 10 0 | 395,503 |
| 1871 | 5,604 | $75\frac{1}{2}$ | 23·0 | 22·0 | 2,049,708 | 366 | 27,148 | 1,986,194 | 354 | 164,188 18 7 | 29 6 0 | 850,256 9 7 | 477,710 |
| 1872 | 5,604 | $75\frac{1}{2}$ | 23·6 | 22·0 | 2,128,379 | 380 | 28,190 | 2,100,577 | 375 | 174,200 12 2 | 31 1 8 | 1,033,181 10 6 | 487,700[1] |

[1] Computed.

IV.—Statement showing the quantity of Material Dredged by the Clyde Navigation Dredging Machines during the last Twenty-Eight Years; also, the Hours the Engines of the Dredger worked during the same Period.

*To face page 156.*

| Years. | Old No. 1. Single Machine, 12 H.P. Greatest Depth can Dredge in, 13 ft. | | New No. 1. Double Machine, 40 H.P. Greatest Depth can Dredge in, 22½ ft. | | No. 2. Single Machine, 16 H.P. Greatest Depth can Dredge in, 14 ft. | | No. 3. Single Machine, 16 H.P. Greatest Depth can Dredge in, 20 ft. | | No. 4. Single Machine, 20 H.P. Greatest Depth can Dredge in, 15 ft. | | No. 5. Single Machine, 24 H.P. Greatest Depth can Dredge in, 18 ft. | | No. 6. Double Machine, 40 H.P. Greatest Depth can Dredge in, 25 ft. | | No. 7. Single Machine, 25 H.P. Greatest Depth can Dredge in, 25 ft. | | No. 8. Single Machine, 75 H.P. Greatest Depth can Dredge in, 25 ft. | | No. 9. Single Machine, 75 H.P. Greatest Depth can Dredge in, 30 ft. | | Totals. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hours. | Cubic Yards. | Hours. | Cubic Yards. | Hours. | Cubic Yards. | Hours. | Cubic Yards. | Hours. | Cubic Yards. | Hours. | Cubic Yards. | Hours. | Cubic Yards. | Hours. | Cubic Yards. | Hours. | Cubic Yards. | Hours. | Cubic Yards. | Hours. | Cubic Yards. |
| 1841–45 | 1,895 | 44,581 | .. | .. | 2,236 | 58,976 | 1,777½ | 41,560 | 1,271 | 32,632 | 2,021 | 56,192 | .. | .. | .. | .. | .. | .. | .. | .. | 9,200½ | 233,944 |
| 1845–46 | 1,171½ | 26,912 | .. | .. | 1,531 | 38,016 | 1,738 | 39,184 | 1,913 | 46,104 | 1,967 | 49,304 | .. | .. | .. | .. | .. | .. | .. | .. | 8,323½ | 199,520 |
| 1846–47 | .. | .. | .. | .. | 1,527½ | 45,944 | 1,841½ | 44,760 | 2,225½ | 66,000 | 1,857 | 45,712 | .. | .. | .. | .. | .. | .. | .. | .. | 7,451½ | 202,416 |
| 1847–48 | .. | .. | .. | .. | 941½ | 28,864 | 1,076¾ | 29,176 | 1,983½ | 45,592 | 1,781¼ | 50,656 | .. | .. | .. | .. | .. | .. | .. | .. | 5,783 | 151,288 |
| 1848–49 | .. | .. | .. | .. | 1,858 | 62,176 | 2,121½ | 71,336 | 923½ | 28,360 | 1,767½ | 51,296 | .. | .. | .. | .. | .. | .. | .. | .. | 6,670½ | 213,168 |
| 1849–50 | .. | .. | .. | .. | 2,371½ | 83,288 | 1,427 | 58,632 | 1,552 | 52,688 | 2,189½ | 84,256 | .. | .. | .. | .. | .. | .. | .. | .. | 7,540 | 278,864 |
| 1850–51 | .. | .. | .. | .. | 2,243½ | 74,200 | 2,376½ | 80,704 | 2,376 | 59,256 | 2,483 | 79,096 | .. | .. | .. | .. | .. | .. | .. | .. | 9,479 | 293,256 |
| 1851–52 | .. | .. | 1,635½ | 69,384 | 2,547 | 95,464 | 2,423 | 62,576 | 2,408½ | 61,072 | 2,654 | 87,976 | .. | .. | .. | .. | .. | .. | .. | .. | 11,688 | 376,472 |
| 1852–53 | .. | .. | 1,846½ | 104,148 | 2,282 | 70,640 | 1,944½ | 40,488 | 1,667 | 46,536 | 2,421½ | 77,352 | .. | .. | .. | .. | .. | .. | .. | .. | 10,161½ | 359,464 |
| 1853–54 | .. | .. | 1,822 | 105,848 | 1,879½ | 59,336 | 1,272 | 48,648 | 1,065 | 40,736 | 1,664 | 47,504 | .. | .. | .. | .. | .. | .. | .. | .. | 7,702½ | 303,072 |
| 1854–55 | .. | .. | 1,699 | 89,728 | 2,597 | 74,344 | 1,379 | 78,200 | 2,329 | 45,176 | 1,456½ | 55,408 | .. | .. | .. | .. | .. | .. | .. | .. | 9,400½ | 342,856 |
| 1855–56 | .. | .. | 2,410½ | 134,352 | 2,305 | 58,448 | 1,878½ | 37,072 | 2,506½ | 51,808 | 1,768½ | 32,160 | 518 | 66,696 | .. | .. | .. | .. | .. | .. | 11,387 | 383,536 |
| 1856–57 | .. | .. | 2,321½ | 125,520 | 2,130½ | 51,520 | 2,178 | 54,536 | 2,170 | 43,296 | 1,470 | 39,096 | 1,592 | 192,008 | .. | .. | .. | .. | .. | .. | 11,862 | 595,976 |
| 1857–58 | .. | .. | 2,437 | 130,912 | 3,162 | 77,576 | 2,108 | 58,504 | 3,470½ | 75,312 | 2,835 | 42,856 | 1,914 | 245,520 | .. | .. | .. | .. | .. | .. | 15,926½ | 630,689 |
| 1858–59 | .. | .. | 3,096½ | 185,816 | 2,829 | 81,024 | 3,503 | 87,000 | 2,905 | 51,664 | 2,390 | 43,784 | 2,231 | 195,720 | .. | .. | .. | .. | .. | .. | 16,954½ | 645,008 |
| 1859–60 | .. | .. | 2,608½ | 150,672 | 2,868 | 67,592 | 3,256½ | 86,632 | 3,007½ | 74,152 | 2,512 | 56,024 | 2,163 | 208,832 | 133 | 5,656 | .. | .. | .. | .. | 16,518½ | 619,560 |
| 1860–61 | .. | .. | 2,492½ | 150,456 | 910½ | 18,088 | 1,817½ | 44,496 | 2,428½ | 61,064 | 2,560¾ | 79,920 | 1,578½ | 163,736 | 2,297 | 75,416 | .. | .. | .. | .. | 14,085½ | 593,176 |
| 1861–62 | .. | .. | 2,326½ | 133,320 | 1,331 | 33,264 | Sold. | | 3,165½ | 76,624 | 2,323¼ | 62,640 | 1,961 | 156,720 | 2,723 | 106,448 | .. | .. | .. | .. | 13,833 | 569,016 |
| 1862–63 | .. | .. | 2,716½ | 158,880 | 1,330¾ | 43,352 | .. | .. | 1,991 | 53,456 | 2,803 | 62,288 | 1,721¼ | 123,656 | 2,091½ | 126,696 | .. | .. | .. | .. | 12,654 | 568,328 |
| 1863–64 | .. | .. | 2,483½ | 145,360 | 1,126 | 33,912 | .. | .. | 2,385½ | 56,792 | 2,024 | 60,888 | 2,679½ | 243,392 | 2,038½ | 93,928 | .. | .. | .. | .. | 12,737 | 632,272 |
| 1864–65 | .. | .. | 2,639 | 146,232 | Sold. | | .. | .. | 2,578 | 73,520 | 2,737½ | 65,656 | 2,859¾ | 321,120 | 2,847½ | 43,912 | .. | .. | .. | .. | 13,661¾ | 650,440 |
| 1865–66 | .. | .. | 1,081¼ | 59,048 | .. | .. | .. | .. | 218 | 7,464 | 828½ | 25,568 | 2,133½ | 162,160 | 1,861 | 55,376 | 1,711½ | 250,520 | .. | .. | 7,864¼ | 560,176 |
| 1866–67 | .. | .. | 1,783½ | 100,084 | .. | .. | .. | .. | Sold. | | 899 | 35,432 | 2,461 | 199,100 | 1,970½ | 72,312 | 2,192¾ | 294,480 | .. | .. | 9,306 | 702,308 |
| 1867–68 | .. | .. | 1,819 | 100,352 | .. | .. | .. | .. | .. | .. | 2,323½ | 83,368 | 2,717¼ | 219,060 | 2,511 | 106,056 | 2,302¼ | 359,440 | .. | .. | 11,763 | 898,276 |
| 1868–69 | .. | .. | 2,386½ | 128,920 | .. | .. | .. | .. | .. | .. | 1,491¼ | 46,472 | 2,554¾ | 258,880 | 2,278 | 37,552 | 2,343¾ | 398,400 | .. | .. | 11,053½ | 870,224 |
| 1869–70 | .. | .. | 1,384¾ | 81,888 | .. | .. | .. | .. | .. | .. | 1,479¾ | 24,720 | 2,851½ | 331,140 | 2,486 | 32,312 | 2,862½ | 446,640 | .. | .. | 11,064½ | 916,700 |
| 1870–71 | .. | .. | 1,831¾ | 122,664 | .. | .. | .. | .. | .. | .. | 2,233 | 65,160 | 2,921 | 243,000 | 2,604½ | 26,720 | 2,419¾ | 430,240 | 166⅔ | 16,320 | 12,176½ | 904,104 |
| 1871–72 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 2,297½ | 48,618 | 2,426 | 276,960 | 2,242 | 37,736 | 2,386¼ | 366,080 | 2,015 | 262,960 | 11,396¾ | 992,354 |
| Total . | 3,066½ | 71,496 | 42,841½ | 2,423,824 | 40,013¼ | 1,156,024 | 31,118¾ | 963,504 | 46,570 | 1,152,304 | 57,238¾ | 1,559,402 | 37,283 | 3,637,700 | 28,083½ | 820,120 | 16,307¾ | 2,545,800 | 2,211½ | 279,280 | 307,734½ | 14,609,454 |

Note.—The number of cubic yards has been made up from the number of punts filled by the dredgers, and on the supposition that each punt load will measure 8 cubic yards in the deposit; and in the case of the hopper barges Nos. 1, 2, 3, and 4, at 240 cubic yards per load, and barges Nos. 5, 6, 7, 8, 9, 10, 11, 12, 13, and 14, at 320 cubic yards per load.

V.—General Dimensions of Dredgers employed on the Clyde in 1872.

| Distinguishing Number. | Year Built. | Length. | Breadth. | Depth. | H.P. | Greatest Depth can Dredge in. | Single Bucket or Double Bucket Ladder. | Remarks. |
|---|---|---|---|---|---|---|---|---|
| | | ft. in. | ft. in. | ft. in. | | ft. in. | | |
| 1 | 1851 | 99·9 | 32·4 | 10·0 | 40 | 22·6 | Double | Punt loading machine. |
| 5 | 1841 | 95·6 | 22·6 | 10·4 | 24 | 18·0 | Single | Do. do. do. |
| 6 | 1855 | 121·0 | 33·6 | 10·0 | 40 | 25·0 | Double | Hopper barge do. do. |
| 7 | 1860 | 108·6 | 23·6 | 9·0 | 25 | 25·0 | Single | Punt do. do. |
| 8 | 1865 | 161·0 | 29·0 | 10·0 | 75 | 28·0 | Do. | Hopper barge do. do. |
| 9 | 1871 | 161·0 | 29·0 | 10·0 | 75 | 30·0 | Do. | Do. do. do. |

## VI.—Lists of Wages of Crews:—

### Of Dredging Machines.

| Year. | Dredging Machine. | Master. | Mate. | Engineer. | Fireman. | Cook. | Bow Craneman. | Stern Craneman. | Arkman. | Deck hands. | Puntmen. | Punt Pumper. | Dredger and Punt Watchman. | Total Crew. | Total Wages per Day. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | s. d. | s. d. | s. d. | s. d. | s. d. | s. d. | s. d. | s. d. | s. d. | s. d. | s. d. | s. d. | | £. s. d. |
| 1870–71. | No. 1. | 5 6 | 3 8 | 6 4 | 3 6 | 3 0 | 3 4 | 3 2 | 3 2 | 2 at 3 0 | 1 at 3 6<br>5 at 3 4 | 3 0 | 2 at 3 0 | 19 | 3 6 10 |
| | No. 5. | 5 0 | 3 8 | 5 0 | 3 2 | .. | 3 4 | 3 2 | .. | 2 at 3 0 | 1 at 3 6<br>3 at 3 4 | .. | 2 at 3 0 | 14 | 2 8 10 |
| | No. 6. | 6 0 | 3 8 | 6 8 | 3 8 | 3 0 | 3 4 | 3 4 | 3 4 | 1 at 3 2<br>2 at 3 0 | .. .. | .. | 1 at 3 0 | 12 | 2 5 2 |
| | No. 7. | 5 0 | 3 8 | 5 10 | 3 2 | .. | 3 4 | 3 2 | .. | 2 at 3 0 | 1 at 3 6<br>2 at 3 4 | .. | 2 at 3 0 | 13 | 2 6 4 |
| | No. 8. | 7 0 | 3 9 | 6 8 | 3 8 | 3 4 | 3 4 | 3 4 | .. | 3 at 3 2<br>1 at 3 0 | .. .. | .. | 1 at 3 0 | 12 | 2 6 7 |
| | No. 9. | 7 0 | 3 10 | 6 8 | 3 10 | 3 4 | 3 4 | 3 4 | .. | 3 at 3 2<br>1 at 3 0 | .. .. | .. | 1 at 3 0 | 12 | 2 6 10 |
| 1871–72. | No. 5. | 5 0 | 4 0 | 5 0 | 3 8 | .. | 3 8 | 3 6 | .. | 2 at 3 4 | 1 at 3 10<br>3 at 3 8 | .. | 2 at 3 4 | 14 | 2 13 0 |
| | No. 6. | 6 0 | 4 0 | 6 8 | 4 0 | 3 4 | 3 8 | 3 8 | 3 8 | 1 at 3 6<br>2 at 3 4 | .. .. | .. | 1 at 3 4 | 12 | 2 8 6 |
| | No. 7. | 5 0 | 4 0 | 5 10 | 3 8 | .. | 3 8 | 3 6 | .. | 2 at 3 4 | 1 at 3 10<br>2 at 3 8 | .. | 2 at 3 4 | 13 | 2 10 2 |
| | No. 8. | 7 0 | 4 1 | 6 8 | 4 0 | 3 8 | 3 8 | 3 8 | .. | 3 at 3 6<br>1 at 3 4 | .. .. | .. | 1 at 3 4 | 12 | 2 9 11 |
| | No. 9. | 7 0 | 4 2 | 6 8 | 4 0 | 3 8 | 3 8 | 3 8 | .. | 3 at 3 6<br>1 at 3 4 | .. .. | .. | 1 at 3 4 | 12 | 2 10 0 |

### Of Steam Hopper Barges.

| Year. | Master. | Mate. | Engineer. | Fireman. | Deck hands. | Cook. | Total Crew. | Total Wages per Day. |
|---|---|---|---|---|---|---|---|---|
| | *s.* *d.* | *s.* *d.* | *s.* *d.* | *s.* *d.* | *s.* *d.* | *s.* *d.* | | £. *s.* *d.* |
| 1870–71 | 7 0 | 4 6 | 5 10 | 3 6 | 2 at 3 4 | 3 4 | 7 | 1 10 10 |
| 1871–72 | 7 0 | 4 6 | 5 10 | 4 0 | 2 at 3 8 | 3 8 | 7 | 1 12 4 |

### Of Tug Steamer.

| Year. | Master. | Mate. | Engineer. | Assistant Engineer. | Fireman. | Coal Trimmer and Cook. | Deck hand. | Puntmen. | Total Crew. | Total Wages per Day. |
|---|---|---|---|---|---|---|---|---|---|---|
| | *s.* *d.* | *s.* *d.* | *s.* *d.* | *s.* *d.* | *s.* *d.* | *s.* *d.* | *s.* *d.* | *s.* *d.* | | £. *s.* *d.* |
| 1870–71 | 6 0 | 4 0 | 5 10 | 2 10 | 3 10 | 2 8 | 3 4 | 1 at 3 6 | | |
| | | | | | | | | 1 at 3 4 | 9 | 1 15 4 |
| 1871–72 | 6 0 | 4 4 | 5 10 | 3 2 | 3 10 | 3 0 | 3 10 | 1 at 3 10 | | |
| | | | | | | | | 1 at 3 8 | 9 | 1 17 6 |

### Of Diving Bells.

| Year. | Master. | Divers. | Cook. | Deck hands. | Watchman. | Total Crew. | Total Wages per Day. |
|---|---|---|---|---|---|---|---|
| | *s.* *d.* | *s.* *d.* | *s.* *d.* | *s.* *d.* | *s.* *d.* | | £. *s.* *d.* |
| 1870–71 | 4 10 | 2 at 4 10 | 3 0 | 5 at 3 0 | 3 0 | | |
| | | 2 at 4 4 | .. .. | .. .. | .. .. | 12 | 2 4 2 |
| 1871–72 | 5 2 | 2 at 5 2 | | | | | |
| | | 2 at 4 8 | 3 4 | 3 at 3 4 | 3 4 | 10 | 2 1 6 |

VII.—Detailed Cost

| Year. | Dredging Machine. | Original Cost of Dredger. | General Character of Stuff Dredged. | Engine Hours Worked. | Cubic Yards Lifted per Engine Hour. | Cubic Yards Lifted. |
|---|---|---|---|---|---|---|
| | | £. | | | | |
| 1870–71 | No. 1 . | 7,923 | Sand, silt, and sewage . . . | 1,831¾ | 66·96 | 122,664 |
| | No. 5 . | 2,000 | Hard till, sand, and gravel . | 2,233 | 29·18 | 65,160 |
| | No. 6 . | 13,663 | Sand, clay, and mud . . . | 2,921 | 83·19 | 243,000 |
| | No. 7 . | 6,655 | Hard till, and clay | 2,604½ | 10·26 | 26,720 |
| | No. 8 . | 17,653 | Sand, silt, till, and gravel . . . | 2,419¾ | 177·80 | 430,240 |
| | No. 9[1] . | 15,000[2] | Sand, and clay . | 166½ | 98·01 | 16,320 |
| | | | | 12,176½ | Average 77·57 | 904,104 |
| 1871–72 | No. 5 . | 2,000 | Till, gravel, sand, and silt . . . | 2,297½ | 21·16 | 48,618 |
| | No. 6 . | 13,663 | Sand, and clayey sand . . . | 2,426 | 114·16 | 276,960 |
| | No. 7 . | 6,655 | Hard till, gravel, sand, &c. . . | 2,242 | 16·83 | 37,736 |
| | No. 8 . | 17,653 | Sand, silt, &c. . | 2,386¼ | 153·41 | 366,080 |
| | No. 9[1] . | 15,000[2] | Till, gravel, clay, sand, and mud . | 2,045 | 128·58 | 262,960 |
| | | | | 11,396¾ | Average 87·07 | 992,354 |

[1] This dredger commenced to work in June, 1871.
[2] Approximate cost, accounts not yet settled.

OF DREDGING.

| Wages of Crew. | | | Coals. | | | Stores. | | | Repairs. | | | Interest and Depreciation, 10 per Cent. | | | Total Cost for the Year. | | | Cost per Cubic Yard. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| £. | s. | d. | £. | s. | d. | £. | s. | d. | £. | s. | d. | £. | s. | d. | £. | s. | d. | d. |
| 869 | 10 | 8 | 183 | 17 | 5 | 57 | 17 | 7 | 994 | 6 | 8 | 792 | 6 | 0 | 2,897 | 18 | 4 | 5·67 |
| 746 | 15 | 9 | 124 | 4 | 8 | 52 | 7 | 8 | 477 | 6 | 4 | 200 | 0 | 0 | 1,600 | 14 | 5 | 5·89 |
| 778 | 6 | 11 | 284 | 15 | 1 | 86 | 19 | 3 | 892 | 19 | 4 | 1,366 | 6 | 0 | 3,409 | 6 | 7 | 3·36 |
| 714 | 6 | 2 | 128 | 13 | 3 | 34 | 4 | 4 | 774 | 2 | 3 | 665 | 10 | 0 | 2,316 | 16 | 0 | 20·81 |
| 678 | 0 | 0 | 371 | 18 | 3 | 182 | 7 | 1 | 1,669 | 6 | 11 | 1,765 | 6 | 0 | 4,666 | 18 | 3 | 2·60 |
| 14 | 14 | 6 | .. | .. | [3] | 70 | 15 | 1 | .. | .. | | 125 | 0 | 0 | 210 | 9 | 7 | 3·09 |
| 3,801 | 14 | 0 | 1,093 | 8 | 8 | 484 | 11 | 0 | 4,808 | 1 | 6 | 4,914 | 8 | 0 | 15,102 | 3 | 2 | Average 4·01 |
| 720 | 2 | 4 | 140 | 8 | 11 | 54 | 7 | 7 | 702 | 11 | 3 | 200 | 0 | 0 | 1,817 | 10 | 1 | 8·97 |
| 694 | 9 | 4 | 232 | 19 | 0 | 112 | 19 | 4 | 1,470 | 4 | 8 | 1,366 | 6 | 0 | 3,876 | 18 | 4 | 3·36 |
| 611 | 17 | 3 | 101 | 13 | 6 | 46 | 1 | 0 | 692 | 9 | 10 | 665 | 10 | 0 | 2,117 | 11 | 7 | 13·46 |
| 679 | 2 | 2 | 462 | 19 | 4 | 187 | 13 | 10 | 1,197 | 7 | 8 | 1,765 | 6 | 0 | 4,292 | 9 | 0 | 2·81 |
| 615 | 0 | 7 | 229 | 4 | 1 | 103 | 18 | 1 | 784 | 2 | 11 | 1,500 | 0 | 0 | 3,232 | 5 | 8 | 2·95 |
| 3,320 | 11 | 8 | 1,167 | 4 | 10 | 504 | 19 | 10 | 4,846 | 16 | 4 | 5,497 | 2 | 0 | 15,336 | 14 | 8 | Average 3·71 |

[3] Account for coals not paid till next quarter.

VIII.—Detailed Cost for Use of Punts Conveying Dredgings.

| Year. | Duties Performed. | Valuation of Punts employed. | Proportion for Repairs. | Interest and Depreciation, 10 per Cent. | Total Cost for the Year. | Cubic Yards Conveyed. | Cost per Cubic Yard. |
|---|---|---|---|---|---|---|---|
| | | £. s. d. | £. s. d. | £. s. d. | £. s. d. | | d. |
| | Conveying Dredgings from :— | | | | | | |
| 1870–71 | No. 1 Dredger . . . . | 9,000 0 0 | 900 0 0 | 900 0 0 | 1,800 0 0 | 122,664 | 3·52 |
| | No. 5 Dredger . . . . | 5,400 0 0 | 540 0 0 | 540 0 0 | 1,080 0 0 | 65,160 | 3·98 |
| | No. 7 Dredger . . . . | 5,400 0 0 | 540 0 0 | 540 0 0 | 1,080 0 0 | 26,720 | 9·70 |
| 1871–72 | No. 5 Dredger . . . . | 5,400 0 0 | 510 0 0 | 540 0 0 | 1,050 0 0 | 48,618 | 5·18 |
| | No. 7 Dredger . . . . | 5,400 0 0 | 510 0 0 | 540 0 0 | 1,050 0 0 | 37,736 | 6·67 |

IX.—Detailed Cost of Conveying Dredgings by Steam Hopper Barges.

| Year. | Duties Performed. | Original Cost of Barges. | Wages of Crews, Coals, and Stores. | Repairs. | Interest and Depreciation, 10 per Cent. | Total Cost for the Year. | Cubic Yards Conveyed. | Average Cost per Cubic Yard. |
|---|---|---|---|---|---|---|---|---|
| | | £. s. d. | £. s. d. | £. s. d. | £. s. d. | £. s. d. | | d. |
| 1870–71 | 10 Barges conveying Dredgings from Dredgers (Nos. 6 and 8) working at Glasgow, Bowling, Port Glasgow, &c., to Loch Long . . . | 51,510 0 0 | 6,917 0 5 | 3,255 7 9 | 5,151 0 0 | 15,323 8 2 | 673,240 | 5·46 |
| 1871–72 | 14 Barges conveying Dredgings from Dredgers (Nos. 6, 8, and 9) working between Glasgow and Port Glasgow; and excavated stuff from Road Diversion at Stobcross, to Loch Long | 73,670 0 0 | 9,839 2 2 | 3,119 9 6 | 7,367 0 0 | 20,325 11 8 | 950,800 | 5·13 |

X.—Steam Hopper Barges.—Working

| Barge. | Original Cost of Barge. | Engine Hours Worked. | Laid up and Repairing, &c. | Wages. | Coals. |
|---|---|---|---|---|---|
| | £. | | days. | £. s. d. | £. s. d. |
| No. 1. . | 5,151 | 1,282½ | 62 | 388 4 5<br>72·63d. | 235 1 4<br>43·97d. |
| No. 2. . | 5,151 | 1,441½ | 45 | 432 12 3<br>72·02d. | 276 7 11<br>46·12d. |
| No. 3. . | 5,151 | 1,453¼ | 48 | 424 7 7<br>70·08d. | 263 3 10<br>43·46d. |
| No. 4. . | 5,151 | 1,430½ | 50 | 414 14 2<br>69·57d. | 276 7 5<br>46·36d. |
| No. 5. . | 5,151 | 1,990½ | 32 | 453 10 0<br>54·69d. | 232 0 7<br>27·96d. |
| No. 6. . | 5,151 | 1,943 | 30 | 474 11 0<br>58·46d. | 311 2 3<br>38·33d. |
| No. 7. . | 5,151 | 1,787½ | 33 | 294 9 1<br>39·53d. | 310 2 11<br>41·64d. |
| No. 8. . | 5,151 | 1,438½ | 81 | 216 19 1<br>36·19d. | 235 1 4<br>39·22d. |
| No. 9. . | 5,151 | 1,602 | 80 | 373 2 6<br>55·9cd. | 260 18 1<br>39·06d. |
| No. 10 . | 5,151 | 1,637¾ | 55 | 415 4 2<br>60·84d. | 268 12 2<br>39·36d. |
| No. 11 . | 5,540 | 1,630½ | 76 | 348 8 5<br>51·23d. | 177 12 5<br>26·14d. |
| No. 12 . | 5,540 | 1,605¾ | 58 | 341 5 9<br>51·01d. | 170 12 11<br>25·50d. |
| No. 13 . | 5,540 | 1,677½ | 60 | 329 13 4<br>47·16d. | 170 13 10<br>24·42d. |
| No. 14 . | 5,540 | 1,335½ | 56 | 277 8 0<br>49·86d. | 133 2 9<br>23·93d. |
| Total . | 73,670 | 22,260⅝ | 706 | 5,184 9 9<br>55·69d. | 3,320 19 9<br>35·68d. |

Expenses during the Year 1871–72.

| Stores. | Repairs. | Interest and Depreciation 10 per Cent. | Total Cost for the Year. | —— |
|---|---|---|---|---|
| £. s. d. | £. s. d. | £. s. d. | £. s. d. | |
| 81 16 3 | 311 3 10 | 515 2 0 | 1,531 7 10 | |
| 15·30d. | 58·22d. | 96·37d. | 286·50d. | Cost per Engine hour. |
| 73 17 6 | 359 16 11 | 515 2 0 | 1,657 16 7 | |
| 12·30d. | 59·91d. | 85·76d. | 276·01d. | ,, ,, |
| 69 0 2 | 197 18 11 | 515 2 0 | 1,469 12 6 | |
| 11·39d. | 32·69d. | 85·07d. | 242·72d. | .. .. |
| 101 0 4 | 238 2 5 | 515 2 0 | 1,545 6 4 | |
| 16·94d. | 39·95d. | 86·42d. | 259·23d. | .. ,, |
| 81 17 1 | 294 14 2 | 515 2 0 | 1,577 3 10 | |
| 9·87d. | 35·54d. | 62·11d. | 190·19d. | .. ,, |
| 95 13 3 | 176 17 7 | 515 2 0 | 1,573 6 1 | |
| 11·78d. | 21·79d. | 63·46d. | 193·83d. | .. ,, |
| 98 7 7 | 192 1 4 | 515 2 0 | 1,410 2 11 | |
| 13·20d. | 25·78d. | 69·16d. | 189·33d. | .. ,, |
| 91 14 6 | 192 1 1 | 515 2 0 | 1,250 18 0 | |
| 15·30d. | 32·04d. | 85·93d. | 208·70d. | .. ,, |
| 98 12 8 | 271 5 10 | 515 2 0 | 1,519 1 1 | |
| 14·77d. | 40·64d. | 77·16d. | 227·37d. | .. ,, |
| 86 4 0 | 261 11 11 | 515 2 0 | 1,546 14 3 | |
| 12·63d. | 38·33d. | 75·48d. | 226·65d. | ,, ,, |
| 84 6 2 | 182 7 0 | 554 0 0 | 1,346 14 0 | |
| 12·41d. | 26·84d. | 81·56d. | 198·25d. | ,, ,, |
| 106 0 1 | 162 9 10 | 554 0 0 | 1,334 8 7 | |
| 15·84d. | 24·28d. | 82·80d. | 199·44d. | ,, ,, |
| 136 2 3 | 156 19 7 | 554 0 0 | 1,347 9 0 | |
| 19·47d. | 22·45d. | 79·26d. | 192·77d. | .. ,, |
| 129 0 10 | 121 19 1 | 554 0 0 | 1,215 10 8 | |
| 23·20d. | 21·92d. | 99·52d. | 218·44d. | ,, ,, |
| 1,333 12 8 | 3,119 9 6 | 7,367 0 0 | 20,325 11 8 | |
| 14·37d. | 33·63d. | 79·43d. | 219·15d. | .. .. |

## XI.—Detailed Cost of Towing Punts by Tug Steamer.

| Year. | Duties Performed. | Original Cost of Tug. | Wages of Crew, Coals, Stores, &c. | Repairs. | Interest and Depreciation, 10 per Cent. | Total Cost for the Year. | Hours Worked. | Average Cost per Hour. | Cubic Yards Conveyed. | Cost per Cubic Yard. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | £. s. d. | £. s. d. | £. s. d. | £. s. d. | £. s. d. | | d. | | d. |
| 1870–71 | Total . . | 4,734 0 0 | 1,069 12 5 | 315 3 0 | 473 8 0 | 1,858 3 5 | 3,416½ | 130·53 | .. .. | .. .. |
| | Towing Punts to and from No. 1 Dredger, Glasgow Harbour to Blythswood Park, &c. . . . . | .. .. | .. .. | .. .. | .. .. | .. .. | 2,221½ | .. .. | 100,352 | 2·88 |
| | Towing Punts to and from No. 5 Dredger, Erskine Ferry, to Dalmuir, Blythswood, &c. . . . . | .. .. | .. .. | .. .. | .. .. | .. .. | 50 | .. .. | 3,704 | 1·76 |
| | Towing Punts to and from No. 7 Dredger, Erskine, & Elderslie, to Dalmuir, Blythswood, &c. . . . | .. .. | .. .. | .. .. | .. .. | .. .. | 39 | .. .. | 2,176 | 2·34 |
| | Replacing Buoys, and other work . . . . | .. .. | .. .. | .. .. | .. .. | .. .. | 1,106 | .. .. | .. .. | .. .. |
| | | | | | | | 3,416½ | | | |
| 1871–72 | Total . . | 4,734 0 0 | 775 6 10 | 148 8 2 | 473 8 0 | 1,397 3 0 | 3,170½ | 105·76 | .. .. | .. .. |
| | Towing Punts to and from Dredgers working at Erskine Ferry, North Barr, Elderslie, Glasgow, &c., and discharging Ground near Erskine Ferry . . . . . | .. .. | .. .. | .. .. | .. .. | .. .. | 2,692½ | .. .. | 73,456 | 3·87 |
| | Towing Punts with Stones, &c., for River Dykes, Weir at Glasgow, &c., and replacing Buoys, and other Work . . . . | .. .. | .. .. | .. .. | .. .. | .. .. | 478 | .. .. | .. .. | .. .. |
| | | | | | | | 3,170½ | | | |

XII.—Detailed Cost of Discharging and Depositing Dredgings from Punts.

| Year. | Where Deposited. | Valuation of Barrows, Planks, &c. | Wages of Men Employed. | Interest and Depreciation, 15 per Cent. | Total Cost for the Year. | Cubic Yards Discharged. | Cost per Cubic Yard. |
|---|---|---|---|---|---|---|---|
| | | £. s. d. | £. s. d. | £. s. d. | £. s. d. | | d. |
| 1870–71 | River Bank west of Dalmuir Burn, by wheeling from Punts, 'beached' and 'afloat' . . . . . | 300 0 0 | 1,598 7 10 | 45 0 0 | 1,643 7 10 | 72,776 | 5·42 |
| | Blythswood Park, by Wagoning, &c., including cost of Slip Docks, Engines, Wagons, &c., by Contract . | . . | . . | (Contractor's Price) . . | . . . | | 10·00 |
| 1871–72 | River Banks near Erskine Ferry, by wheeling from Punts, 'beached' and 'afloat' . . . . . | 300 0 0 | 2,148 15 11 | 45 0 0 | 2,193 15 11 | 85,520 | 6·15 |

XIII.—General Table showing Total Cost

| Year. | Dredging Machine. | General Character of Stuff Lifted, and Locality where Dredged. | Total Cubic Yards Lifted. |
|---|---|---|---|
| 1870–71 | No. 1 . . | Sand, silt, and sewage, from Upper Harbour and Lower Harbour . . | 122,664 |
| | No. 5 . . | Hard till, gravel, and sand, from Erskine Ferry, &c. . . . . | 65,160 |
| | No. 6 . . | Sand, clay, and mud, from Port Glasgow, &c. . . . . | 243,000 |
| | No. 7 . . | Hard till, and clay, from Erskine Ferry, Elderslie, &c. . . . . | 26,720 |
| | No. 8 . . | Sand, silt, till, and gravel, from Glasgow Harbour and Bowling Harbour, &c. | 430,240 |
| | No. 9 . . | Sand, and clay, from Govan Ferry. . | 16,320 |
| | | | 904,104 |
| 1871–72 | No. 5 . . | Till, gravel, sand, and silt, from Erskine Ferry, North Barr, Rashielie, &c. . . . . | 48,618 |
| | No. 6 . . | Sand, and clayey sand, from between Finlayston Channel and Erskine Ferry . . . . . | 276,960 |
| | No. 7 . . | Hard till, gravel, and sand, &c., from Erskine Ferry, North Barr, Elderslie Rock, &c. . . . . | 37,736 |
| | No. 8 . . | Sand, silt, &c., from Glasgow Harbour, and west of Dalmuir Burn . | 366,080 |
| | No. 9 . . | Till, gravel, clay, mud, and sand, from Wester Shiels, Govan, Overnewton, Plantation Quay, &c. . . . . | 262,960 |
| | | | 992,354 |

Dredgers Nos. 1, 5, and 7, are punt loading machines.

[1] Contractor's Price for discharging at Blythswood Park, including slip

[2] Discharging by Trustees' men on river banks near Erskine Ferry,

per Cubic Yard for Dredging and Depositing.

| Cubic Yards Lifted per Engine Hour. | Cost per Cubic Yard. | | | | | Total Cost per Cubic Yard. |
|---|---|---|---|---|---|---|
| | Dredging. | Average cost of Carrying and Depositing by Barges. | Towing Punts to Discharging Ground. | Discharging Dredgings from Punts. | Punts and Boats used. | |
| | *d.* | *d.* | *d.* | *d.* | *d.* | *d.* |
| 66·96 | 5·67 | .. .. | 2·88 | 10·00[1] | 3·52 | 22·07 |
| 29·18 | 5·89 | .. .. | 1·76 | 5·42[2] | 3·98 | 17·05 |
| 83·19 | 3·36 | 5·46 | .. .. | .. .. | .. .. | 8·82 |
| 10·26 | 20·81 | .. .. | 2·34 | 5·42[2] | 9·70 | 38·27 |
| 177·80 | 2·60 | 5·46 | .. .. | .. .. | .. .. | 8·06 |
| 98·01 | 3·09 | 5·46 | .. .. | .. .. | .. .. | 8·55 |
| Average 77·57 | Average 4·01 | 5·46 | Average 2·83 | .. .. | .. .. | .. .. |
| 21·16 | 8·97 | .. .. | 3·87 | 6·15 | 5·18 | 24·17 |
| 114·16 | 3·36 | 5·13 | .. .. | .. .. | .. .. | 8·49 |
| 16·83 | 13·46 | .. .. | 3·87 | 6·15 | 6·67 | 30·15 |
| 153·41 | 2·81 | 5·13 | .. .. | .. .. | .. .. | 7·94 |
| 128·58 | 2·95 | 5·13 | .. .. | .. .. | .. .. | 8·08 |
| Average 87·07 | Average 3·71 | 5·13 | 3·87 | 6·15 | Average 5·84 | Average 9·95 |

Dredgers Nos. 6, 8, and 9, are barge loading machines.

docks and wagoning, for a distance of about ¾ mile.

by wheeling from punts, 'beached' and 'afloat.'

XIV.—Abstract Statement of the Annual Revenue of the Clyde Trust, from July, 1752, to the 30th of June, 1872.

| | £. | s. | d. |
|---|---|---|---|
| From July, 1752, to July . . 1770 | 147 | 0 | 10 |
| One year to do. 1771 | 1,044 | 10 | 0 |
| 1772 | 1,220 | 1 | 9 |
| 1773 | 1,494 | 1 | 0 |
| 1774 | 1,454 | 4 | 4 |
| 1775 | 402 | 3 | 8 |
| 1776 | 1,984 | 0 | 7 |
| 1777 | 1,397 | 0 | 7 |
| 1778 | 1,733 | 19 | 5 |
| 1779 | 1,540 | 1 | 8 |
| 1780 | 1,515 | 8 | 4 |
| 1781 | 1,721 | 5 | 8 |
| 1782 | 1,420 | 16 | 8 |
| 1783 | 1,450 | 16 | 8 |
| 1784 | 1,120 | 0 | 0 |
| 1785 | 3,256 | 18 | 10 |
| 1786 | 1,980 | 14 | 10 |
| 1787 | 1,975 | 16 | 4 |
| 1788 | 2,064 | 5 | 9 |
| 1789 | 2,153 | 15 | 6 |
| 1790 | 2,239 | 0 | 4 |
| 1791 | 3,175 | 14 | 1 |
| 1792 | 2,739 | 5 | 7 |
| 1793 | 2,840 | 17 | 11 |
| 1794 | 2,936 | 14 | 11 |
| 1795 | 2,836 | 5 | 9 |
| 1796 | 3,649 | 14 | 4 |
| 1797 | 3,182 | 6 | 0 |
| 1798 | 3,199 | 1 | 6 |
| 1799 | 3,233 | 18 | 3 |
| 1800 | 3,319 | 16 | 1 |
| 1801 | 3,400 | 10 | 9 |
| 1802 | 4,085 | 15 | 11 |
| 1803 | 4,640 | 16 | 10 |
| 1804 | 4,193 | 7 | 7 |
| 1805 | 4,065 | 10 | 5 |
| 1806 | 4,299 | 14 | 3 |
| 1807 | 5,000 | 5 | 9 |
| 1808 | 5,472 | 0 | 9 |
| 1809 | 5,407 | 9 | 8 |
| 1810 | 6,676 | 7 | 6 |
| 1811 | 4,755 | 3 | 8 |
| 1812 | 4,597 | 19 | 7 |
| 1813 | 5,169 | 13 | 9 |
| 1814 | 5,275 | 6 | 11 |
| 1815 | 5,902 | 2 | 8 |
| 1816 | 5,843 | 7 | 8 |
| 1817 | 7,028 | 0 | 7 |
| 1818 | 7,732 | 18 | 11 |
| 1819 | 7,386 | 2 | 10 |
| 1820 | 6,328 | 18 | 10 |
| 1821 | 8,070 | 2 | 2 |
| Carried forward . £ | 179,761 | 14 | 2 |

| | £. | s. | d. |
|---|---|---|---|
| Brought forward . | 179,761 | 14 | 2 |
| 1822 | 7,984 | 3 | 8 |
| 1823 | 8,380 | 16 | 4 |
| 1824 | 8,555 | 0 | 0 |
| 1825 | 8,367 | 11 | 7 |
| 1826 | 16,204 | 6 | 6 |
| 1827 | 14,316 | 15 | 9 |
| 1828 | 17,669 | 14 | 10 |
| 1829 | 20,194 | 10 | 4 |
| 1830 | 20,296 | 18 | 6 |
| 1831 | 18,932 | 0 | 7 |
| 1832 | 22,496 | 0 | 3 |
| 1833 | 21,578 | 5 | 2 |
| 1834 | 22,859 | 14 | 10 |
| 1835 | 33,676 | 16 | 3 |
| 1836 | 37,544 | 5 | 5 |
| 1837 | 37,644 | 16 | 0 |
| 1838 | 39,030 | 1 | 0 |
| 1839 | 47,879 | 11 | 10 |
| 1840 | 46,536 | 14 | 0 |
| 1841 | 49,665 | 15 | 7 |
| 1842 | 40,678 | 16 | 8 |
| 1843 | 43,301 | 2 | 0 |
| 1844 | 41,286 | 18 | 8 |
| 1845 | 45,868 | 10 | 11 |
| 1846 | 51,198 | 12 | 2 |
| 1847 | 59,017 | 2 | 9 |
| 1848 | 60,621 | 8 | 1 |
| 1849 | 59,034 | 14 | 1 |
| 1850 | 64,243 | 14 | 11 |
| 1851 | 68,875 | 4 | 9 |
| 1852 | 76,077 | 9 | 4 |
| 1853 | 77,919 | 18 | 6 |
| 1854 | 86,580 | 5 | 11 |
| 1855 | 73,943 | 9 | 1 |
| 1856 | 74,995 | 7 | 9 |
| 1857 | 82,797 | 10 | 7 |
| 1858 | 78,783 | 17 | 6 |
| 1859 | 90,816 | 17 | 7 |
| 1860 | 97,983 | 18 | 1 |
| 1861 | 105,768 | 11 | 0 |
| 1862 | 111,493 | 10 | 2 |
| 1863 | 118,083 | 7 | 10 |
| 1864 | 121,380 | 13 | 9 |
| 1865 | 121,587 | 11 | 11 |
| 1866 | 125,787 | 10 | 0 |
| 1867 | 131,892 | 2 | 6 |
| 1868 | 143,840 | 17 | 3 |
| 1869 | 150,136 | 4 | 5 |
| 1870 | 164,093 | 2 | 10 |
| 1871 | 164,188 | 18 | 7 |
| 1872 | 174,200 | 12 | 2 |
| Total . . . £ | 3,586,053 | 14 | 4 |

XV.—Abstract Statement of the Total Expenditure of the Clyde Trust, from the Year 1770 to the 30th of June, 1872.

| | £. | s. | d. |
|---|---|---|---|
| General management, officers' salaries, &c. | 224,587 | 12 | 10 |
| General expenditure, repairs, and 'up-keep' of works, damage to fishings, &c. | 241,048 | 17 | 6 |
| Extraordinary repairs; Parliamentary opposition, &c. | 50,614 | 16 | 10 |
| Crane wages and repairs | 26,812 | 5 | 2 |
| Ferries, wages, and repairs of boats | 57,272 | 0 | 11 |
| Ground annuals and feu-duties | 160,190 | 12 | 4 |
| Law and Parliamentary expenses | 55,648 | 18 | 6 |
| Police | 76,982 | 17 | 7 |
| Rhones and planks for shipping | 15,444 | 13 | 7 |
| Water for supply of vessels | 18,007 | 7 | 5 |
| Taxes | 48,024 | 13 | 5 |
| Lighthouses on river | 9,802 | 0 | 4 |
| Interest on borrowed money | 1,390,947 | 18 | 0 |
| Dredging in river and harbour | 517,262 | 2 | 11 |
| Repairs of machines, punts, &c., including new machines, tug boats, barges, punts, and machinery | 411,414 | 18 | 4 |
| Land purchased for enlargement of harbour | 724,453 | 8 | 3 |
| Ditto for widening river | 164,838 | 0 | 0 |
| New hall and offices for Trustees | 9,215 | 4 | 5 |
| Acts of Parliament | 54,031 | 15 | 9 |
| Construction of works—harbour | 751,210 | 2 | 5 |
| Ditto —river | 404,677 | 1 | 6 |
| Engineering and surveying | 17,710 | 2 | 7 |
| Ballast | 1,203 | 0 | 2 |
| Kingston dock (exclusive of land) | 84,544 | 5 | 4 |
| Dumbarton exemptions | 5,097 | 5 | 2 |
| Dalmuir workshops | 24,205 | 14 | 5 |
| Harbour ditto | 1,817 | 9 | 3 |
| Steam ferry-boats | 3,824 | 19 | 8 |
| Swinging buoys in Gare Loch | 1,154 | 14 | 10 |
| Swing bridge at Kingston Dock | 12,683 | 5 | 0 |
| Graving dock—exclusive of land | 29,129 | 3 | 11 |
| Stobcross dock—ditto | 1,124 | 6 | 4 |
| Total expenditure | £5,594,981 | 14 | 8 |

[Mr. J. F. Bateman, F.R.S.

Mr. J. F. Bateman, F.R.S., said, from his long connection with the Clyde, he might be permitted to commence the discussion. He was quite sure the Meeting had been interested by the Paper, but it might possibly seem to some of the Members that it might have been written by a Glasgow antiquarian, historian, or statistician, inasmuch as it gave but little professional or engineering account of the works by which, during the last hundred years, the Clyde had been brought into its present condition. When, however, the Paper was read in detail, it would be found that much information which appeared to be wanting was really contained in it. He might state that he believed the Author intended at a future time to give—beyond the history of the navigation and of its progress—a description of the engineering processes which had brought about the great results attained. It appeared that, though, some two hundred years ago, the inhabitants of Glasgow made some attempts to improve the bed of the river, it was not until 1768, that any decided course of improvement was determined upon. The proposals of Golborne were then adopted, and from his recommendations the whole of the operations carried out, from that time to the present, had probably originated.

Although Smeaton, in 1765, reported upon the Clyde, Golborne was the first person to determine and recommend the means by which improvements could be brought about. When it was considered that one hundred years ago there were only 12 in. to 15 in. of water in the channel of the river where there were now 14 ft.; that vessels of only 3 ft. draught could pass where now vessels of 22 ft. draught could ride with ease and safety; and, further, that the tide, which occupied 3 hrs. between Greenock and Glasgow, now accomplished the same distance in 1 hr. 5 mins., those results must be regarded as of a most gratifying character. Those improvements had been effected, first, by narrowing the river, by means of groynes, or jetties, as Golborne had recommended, and in addition, by removing shoals and obstructions which impeded the flow of the water. Inasmuch as the river was in many parts too wide, and spread over extensive sand banks, it was considered desirable to concentrate its force in a narrower channel, in order that, after the removal of the gravel on the surface, the increased velocity of the stream should work its own way upon the sandy beds.

Thirteen years after the first introduction of the groynes, namely, in 1781, Golborne reported his great gratification that, though he only expected, by the works proposed in his first report, to get a depth of some 4 ft., a depth of 12 ft. or 14 ft. had been obtained

by the simple means he had recommended. The process of putting in groynes, or jetties, was, on the recommendation of Rennie, carried out to a still greater extent, and their number was increased from fifty to more than five hundred. Subsequently, on the advice of Telford, the groynes were shortened, and retaining walls were put in from groyne to groyne, to prevent interruption in the velocity and to secure uniform scouring effects from the current of the river. The channel had since, from time to time, been enlarged, to such an extent that in effect the dimensions of the river now differed greatly from what they were formerly. Its width at the Broomielaw, which was 160 ft., or 180 ft., fifty years ago, was now 450 ft., or more; and it would bear vessels afloat of from 20 ft. to 23 ft. draught at high water, and from 14 ft. to 16 ft. draught at low water. The present object of the Trustees was to deepen the channel at low water to 20 ft. The greatest credit was due to all connected with the management of the river Clyde for the foresight, the energy, and the admirable manner in which they had administered their trust; and also to the various engineers for the skill they had displayed; and to no one more, perhaps, than to the Author, who had modestly refrained from mentioning the very considerable improvements effected during the years he had been in charge of the river, although they had still further rendered it conducive to the prosperity of the district, and to the convenience and advantage of the commerce of the world.

It would be interesting to those who had listened to the successive modes adopted for deepening the channel by dredging, to hear the gradual results that were obtained by that operation. Thus, in those portions of the channel where, from 1755 to 1768, vessels could pass which drew only 3 ft. of water, the available depth was gradually improved up to 1830, to 15 ft.; in 1839, to 17 ft.; in 1854, to 19 ft.; in 1861, to 20 ft.; in 1862, to 21 ft.; in 1870, to 22 ft.; and works were now in contemplation for obtaining a greater depth. During the last twenty-eight years there had been an amount of material removed by dredging equal to 15,000,000 cubic yards, or an average of about 500,000 cubic yards per annum for twenty-eight years. The quantity dredged last year was about 1,000,000 cubic yards. The Meeting might therefore infer the beneficial results which would accrue from that amount of excavation, and from the still greater improvements which were yet likely to take place. He would not now occupy the time by entering further into particulars, which he should otherwise have been happy to give; but would express the great gratification which this Paper had afforded him. He

was sure the Institution never had had a Paper containing more valuable information, and especially on the subject of dredging. He believed there was scarcely an instance in which the cost of dredging, according to the character of the material excavated, including the expense of repairs, had been more economically performed, ranging as it did from about 12*d.* or 14*d.* per cubic yard for gravel and till, to 2½*d.* and 3*d.* per cubic yard for sand and silt; nor, he believed, had the material ever been carried in hopper barges a distance of twenty-seven miles, and disposed of at so small an expense as that of 5½*d.* per cubic yard. The whole management of the Trust had been characterised by similar economy. The engineering works had been carried out with great skill, and he believed there was no river in the world that had derived more beneficial results from engineering science.

Mr. Redman said no river had attracted more attention, none had been more written about, or had engaged a larger amount of engineering talent, or had more readily returned its equivalent in the increased commerce of the metropolis situated upon it, than the River Clyde. He would, in the first place, draw attention to a Paper read before the Institution on March 24, 1846, "On the Estuary of the River Severn."[1] The discussion upon that Paper diverged into a discussion upon the Clyde, and a number of material facts were given connected with that river which had been placed succinctly before them in the present Paper. The Author correctly stated that as far back as the reign of Queen Mary, in 1550, the first attempt was made to improve the river, from its lower parts to Glasgow, by means of statute labour; but the means were inadequate to the end. In 1759, an Act was obtained for the formation of locks; happily, for Glasgow, never carried out. In 1806, Smeaton proposed a lock across the river. Fortunately, that proposition was also not acted upon; but it was the advice offered by Golborne, Rennie, and other distinguished Engineers, to throw out jetties—which had been subsequently connected together by parallel banks—that had produced the results detailed by the last speaker. Mr. Redman had with him the deposited Parliamentary plans of 1836, and of 1839. The Author had very properly, in his historical Paper, given due credit to those plans. Mr. Redman had marked in pencil, from Glasgow downwards, the widths laid down by Mr. Logan, the then Engineer of the Clyde Trustees, endorsed by Mr. Walker, and afterwards acted upon; and Mr. Redman believed, as the Author stated, if those lines were compared with the lines on

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. v., p. 300.

the Admiralty chart, they would be found to have been acted upon in the improvements of the Clyde in the same way as the lines for the Thames embankment, from the same authority, had been adhered to. The results of the works upon the Clyde had been so extraordinary that he did not think it would be a reiteration to state a few facts which did not appear in the Paper. 3 ft. 3 in. was the depth of water at the time of Telford, and at the Broomielaw there was now the same rise of tide as at Greenock, with 10 ft. or 11 ft. depth of water at low water. Practically, the channel from Greenock to Glasgow was now level. Instead of being a highly inclined slope, and an inclined plane of water diminishing upwards, there was in effect a horizontal bed from Greenock to Glasgow, and there was the same rise of tide at Glasgow as at Greenock. He believed the tidal observations made by the Author, borne out by the experience of other rivers, showed what appeared at first sight an anomaly. There was, in fact, as high a 'back range' of tide at high water at Glasgow as at Greenock, and a lower ebb at Glasgow by 15 in. than at Greenock. The same held good in the Thames; but the zeros of the tide gauges had never been connected by spirit-levels. There was no doubt as great an oscillation of tide at London Bridge as at Gravesend, and at spring tides it was well known there was also a lower ebb. The same phenomena applied to the Clyde between Glasgow and Greenock, and the explanation was simple enough, namely, there was a large tidal estuary flowing out of the upper reaches of the river. The tide was ebbing in the upper river, and the tide of the lower river, rising earlier, met the ebb of the upper river; so that there was a higher oscillation of water at Glasgow than at Greenock. This apparent paradox was pointed out in the discussion upon a Paper read before the Institution, November 20, 1860, "On the River Orwell and the Port of Ipswich."[1] That Paper had created some divergency of opinion. Its Author showed by tidal observations—though they were not connected with spirit-levels—that there was a higher rise at Ipswich, by nearly 2 ft. 3 in., than there was at Harwich. That fact certainly appeared anomalous, and inquiries were made whether low water was higher at Ipswich than at Harwich, and whether the increase of rise was at high water. The same occurred on a large scale in the estuary of the Bristol channel. At the Flat Holmes there was a rise of tide of 36 ft. to 41 ft., and a 'heading-up' of a tidal wave of 60 ft. at Chepstow. It was clear in that case, with deep water and a funnel shape, the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xx., p. 4.

lift of water there, must be on the surface, the low water at Chepstow being higher than at the Flat Holmes; and in the same way the high water was elevated at Chepstow. The same argument hardly held good in the case of the Clyde. The Thames had a large outfall, with a great breadth of deep water. That was not the case of the Clyde. Although it hrd a large estuary at Port Glasgow, where it was two miles to three miles across, yet the navigable channel at low water, opposite Port Glasgow, was proportionably not much larger, so that the tidal wave operated upon a comparatively narrow channel downward as well as upward. The tidal wave was not propagated in the same degree as in the Thames, or in the large estuary of the Severn.

The commercial results at Glasgow were so marvelous, that Mr. Redman simply referred to them as showing the great benefits that were produced by engineering works of the character described. The early reports of Smeaton, Telford, and Rennie showed that the river was navigable only for barges to Glasgow. At the present time the export and import tonnage of Glasgow amounted to the extraordinary sum of 2,500,000 tons; that was to say, the commerce of the port of Glasgow was equivalent to half the foreign tonnage of London or of Liverpool. That result, compared with the early condition of the river, was so remarkable, and so exemplified the effects of the works which had been executed, that Mr. Redman thought it was deserving of notice. With regard to the propagation of the wave, the Author of the Paper now before the Institution stated that, the difference of time between Greenock and Glasgow, at an early period of the history of the river, was from 2 hrs. to 3 hrs. In the report of Mr. David Logan, an old officer of the Clyde Trust, under date October 5th, 1835, the difference at that period was about 1 hr. 45 mins.[1] On the Admiralty chart of 1860, the difference was there defined to be 1 hr. 15 mins.; and now, on the authority of the Author, it was stated to be only 1 hr. Those results were remarkable. In the Thames there had been a corresponding acceleration of the tide due to similar works, but not in the same degree. Then, again, with regard to the height of spring tides—in evidence on the Clyde Navigation Bill of 1836, the spring tide at Port Glasgow was stated to be 10 ft. 10 in., while at the Broomielaw it was 6 ft. The Admiralty chart of 1860 showed that at Glasgow it was then 12 ft., and at Greenock 11 ft. The Author stated it was now somewhat

[1] *Vide* "Tidal Harbours Commission. Appendix (C.) to Second Report of the Commissioners, with supplement and index," page 450.

increased. A large body of evidence was taken by the Tidal Harbours Commission on the state of the river in 1845, and Mr. Redman had an extract from their report which he thought was worth referring to. Speaking of the great development of Glasgow, the Commissioners said :—"But engineering skill being not only slow in its development, but having often to struggle with prejudice and self-interest, it has now been discovered that many of the plans of the Clyde Trustees were short-sighted; that in order to continue their improvements in deepening their river, they must now submit to a large outlay for rebuilding bridges, the foundations of which were not laid deep enough; that weirs have been permitted across the river, nay, sanctioned by Act of Parliament [49 Geo. III. cap. 74], so as to prevent the flow of the tide above the city, and stop all navigation above the bridges; that a considerable expense for dredging might have been saved if the natural flow of the tidal water had been properly directed; the harbour space might have been enlarged, and the general depth of water throughout the river increased; and that, with all these improvements, the dues on shipping might have been lightened, and the ports of Greenock and Port Glasgow, at the mouth of the Clyde, might have been spared a large expenditure in the construction of docks, made in expectation of traffic which it is not probable will ever now be realised."[1] It was obvious that the preceding strictures of the Tidal Harbours Commission were not tenable. The works referred to were now in course of extension. The present tonnage of Glasgow and its insignificant amount at Greenock and Port Glasgow sufficiently stultified them. They were as follows :—

| | Tons. |
|---|---|
| Glasgow . . . . . | 2,378,961 |
| Port Glasgow . . . . . | 82,611 |
| Greenock . . . . . | 769,202 |

The large works recently constructed and still being carried out at the two latter ports also showed forcibly enough the development of steam shipping; and the yet continuing increase to the maritime supremacy of Glasgow, was remarkably and entirely the result of the works which had been described in the Paper.

The following details as regarded the cost of dredging might possibly be of interest :—

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[1] *Vide* "Tidal Harbours Commission. First Report of the Commissioners," page vi.

| | Per cubic yd. s. | d. |
|---|---|---|
| 1835. River Thames. Blackfriars, below low water; mud, sand, and gravel . | 1 | 11 |
| Do., Whiting shoal, concreted mass, to 15 ft. below low water . . | 1 | 0 |
| Do., above bridge, gravel into barges, 5*d*. . . . | 1 | 2 |
| Additional, for lighterage below, 9*d*. to 1*s*. . . . | to 1 | 5 |

| | Per cubic yd. s. | d. |
|---|---|---|
| River Clyde—1841 . . . | 1 | 6 |
| Do. 1842 . . . | 0 | 10½ |
| Do. 1843 . . . | 0 | 8 |
| Do. 1844 . . . | 0 | 8 |
| Aberdeen Harbour . . . | 0 | 4 |
| Ayr ,, . . . | 0 | 5 |
| Leith ,, . . . | 1 | 0 |
| Perth . . . . . | 0 | 3 |
| Do., Clay . . . . . | 0 | 3½ |
| Yarmouth . . . . . | 0 | 5 |

Lord Blantyre, through the Secretary, said, he had never been able to understand the boasting there was about the improvement of the river Clyde. His estate ran 5 miles along the southern shore, and 2 miles on the northern shore of that river. The state of the river throughout those 5 miles was most humiliating. In effect it was treated as Scotch farms were formerly—the lands near the houses got all the manure, and were fair to look upon; the outlying lands got little or none, and became poorer every year. So that middle section of the Clyde seemed to go back, compared with the improvements nearer Glasgow.

He would offer a few remarks as regarded the unimproved state of a considerable portion of the river, and having been a 'residenter' upon the Clyde for the best part of his life, he submitted the following propositions:—1. That the river Clyde had not been improved to an extent at all commensurate with the length of time the work had been in hand, or the mechanical appliances and funds the Clyde Trustees had possessed. The time had been 103 years—the appliances, 53 years of dredging without steam, and 50 years of dredging with steam (1824-1873). The amount of money he could not give. 2. That the river was not likely to be adequately improved so long as the Trust was exclusively in the hands of the inhabitants of Glasgow.

When the Magistrates of Glasgow, a hundred years ago, applied to Civil Engineers to give the town a better connection with the sea, the Magistrates received the reply, that, if a certain principle was followed out, the sea would be brought up to the town. That principle was to bring the river into the best form for transmitting the tidal wave, or, in other words, to give the bottom and sides of the river such a form as would cause the sea tides to rise to the greatest height, and in the shortest time, in the harbour of Glasgow. Where that principle had been carried out the success had been very marked, but how far it had been carried out might be brought to a crucial test by any one. The following data as

regarded the tides were taken from the chart of the Clyde prepared by Captain E. K. Calver, F.R.S., Assoc. Inst. C.E., in 1860, and showed the velocity of the tides in different stages of the river:—

| | h. | m. |
|---|---|---|
| High water, Full and Change, at Greenock . . | 12 | 8 |
| „ at Dumbarton rock . . . . . | 12 | 20 |
| Tide rose about 7 miles in . . . . | 0 | 12 |
| High water, Full and Change, at Dumbarton rock | 12 | 20 |
| „ at Yoker . . . . . | 1 | 15 |
| Nearly 8 miles in . . . . . | 0 | 55 |
| High water, Full and Change, at Yoker . . . | 1 | 15 |
| „ at Glasgow . . . . . | 1 | 25 |
| About 5½ miles in. . . . . | 0 | 10 |
| High water, Full and Change, at Glasgow . . | 1 | 25 |
| „ at Greenock . . . . . | 12 | 8 |
| Total distance traversed in . . . . | 1 | 17 |

It appeared, therefore, that high water occurred at Greenock at full and change of the moon at 12 h. 8 m., and at Glasgow at the same periods, at 1 h. 25 m., or high water at Glasgow was 1 hr. 17 mins. later than high water at Greenock, but the progress of the tidal wave along the river was not uniform. That was the test by which Lord Blantyre proposed to prove the backward state of the river improvement.

In its first stage, the tidal wave reached Dumbarton rock at 12 h. 20 m., or only 12 mins. later than it reached Greenock, though the distance was about 7 miles. In the second stage, it reached Yoker at 1 h. 15 m., and, therefore, took 55 mins. to pass over about 8 miles. In the third stage, it reached Glasgow at 1 h. 25 m., thus overcoming the last 5½ miles in 10 mins., or at about the same speed as from Greenock to Dumbarton, which was not a little remarkable. The last stage nearest to Glasgow represented the improved portion of the river. The middle stage, the unimproved portion, where the wave took 55 mins. to overcome 8 miles. The first stage nearest the sea had more advantages by nature, though he readily admitted it had been greatly improved by dredging a deeper and straighter channel.

It was some time since the chart of 1860 was prepared; the tide took then 1 hr. 17 mins. to pass from Greenock to Glasgow.

Mr. Bateman had stated that it now only took 1 hr. 5 mins. That showed a difference of only 12 mins.; but Lord Blantyre happened to know that that was much less acceleration than the tide was capable of, because he lived opposite to a part of the river which was still a wilderness of waters—a chaos—a negation of all engineering principles.

The jetties recommended by John Golborne had been removed. The longitudinal, or parallel, or connecting, dyke of John Rennie—which had never been completed—had been left for years standing, for a length of more than 3 miles, much above half-tide high, in the middle of the river—though on one side of the channel—unconnected anywhere with the land—inviting the tides to pass up on one side of it and return by the other, a result which probably only extensive dredging in the channel had hitherto prevented taking place. The works of the late James Walker had not been commenced. The dredging of the old channel, planned by John Rennie in 1807—but executed narrower at Dunglas Castle than he advised, for the channel was only 400 ft. wide there at present—was all that had been done for some miles above Dumbarton rock; but so long as the trade could make its way to Glasgow the inhabitants of that city need not to care.

The great trade of Glasgow was no more proof that the river had been improved than the overland trade from China to Russia was a proof that Central Asia afforded good and peaceable roads for caravans. It might be noticed every day that trade overcame all obstacles; nothing could prevent it going where it was wanted.

Lord Blantyre would now turn to the second proposition which he had adduced. In 1840, the late James Walker was asked the following question in Committee:—"How long would it take to carry out the widening and deepening of the River Clyde according to his plans?" He answered:—"It would take fifteen years with our present plant." More than twice fifteen years had passed; the plant had been greatly increased, and yet a considerable part of Mr. Walker's plans had not even been commenced, and there was no certainty that they would soon, or, indeed, ever be carried out. The Trust, composed exclusively of inhabitants of Glasgow, expended the funds in works in and near Glasgow. Lord Blantyre considered that the river dues should be separated from the harbour dues, and spent exclusively on the river, and that the Trust should be opened to representatives from the adjoining counties and the nation. The consumer really paid the rates of river and harbour; so a great part of Scotland was a contributor to those funds, and might take part in seeing them properly applied. It was not the

general interest of the country that was now studied, but the particular interest of Glasgow. The inhabitants of Glasgow seemed to grudge everything spent upon the river, but nothing which was spent upon their harbour and dock works; and as the monies levied from the public might be expended upon those works to any extent, it was obvious that the river would never be likely to be improved throughout its entire course by trustees chosen as at present.

Mr. James Abernethy said, the subject brought forward in the Paper was one which he considered to be of Imperial importance, inasmuch as it referred to the improvement of one of those great public water highways—the tidal and navigable rivers of the United Kingdom. He used the term 'public highways,' because he had long been of opinion that all works tending to impede the free tidal flow of navigable river currents, and which were often constructed to serve mere private ends, were most serious interferences with the public interests.

Amongst the various navigable tidal rivers of Great Britain the Clyde stood prominently forward as an example of a river improved by following out—what he considered—a sound engineering principle, namely, that of bringing the river into a state of equilibrium by the construction of works to create a current proportionate to the size and form of the channel, and the nature of its bed. All the engineers employed on the Clyde—Smeaton, Golborne, Watt, Telford, Rennie, and Walker—had acted upon the principle of increasing the tidal volume, and prolonging its flow into the upper reaches of the river, by dredging and by filling up indents which tended to create eddies and arrest the free flow of the current. In the first instance jetties were projected from the foreshore, with a view to equalise the sectional area of the river. Although by accretion between those jetties the parallelism of the river banks was to a certain extent insured, yet the flowing and ebbing currents, impinging upon the ends and sides of the jetties, created great irregularities in the bed of the river; and consequently, more recently, the system of parallel training walls had been adopted. That, with the addition of dredging, had to a great extent improved the river Clyde. He thought the result in the case of that river, and also of the Tyne, demonstrated most clearly that the formation and conservation of the navigable channels of tidal rivers were dependent upon the tidal ebb and flow, and not upon the natural fresh water stream of the river or the occasional effects of floods or freshes. That theory was borne out in the case of rivers where an opposite system had been pursued, such as the

Dee and the Nene, where works had been carried out by which the quantity of tidal water had been diminished—the natural discharge remaining in its normal state dependent on the watersheds, which were defined and constant. He was quite aware that, for some years past, the theory had been broached that the maintenance of the channels of navigable rivers was to a great extent dependent upon the action of freshes, and that it was possible to maintain their depth by occasional discharges, through sluices in dams near their entrances, at or near the period of low water. Now, he contended that it was impossible to maintain the entrance channels of rivers by a stream, whatever its velocity might be, which did not possess the hydrostatic element of weight, or an equivalent to the ebb and flow of a tidal column constantly passing up and down, with a scouring power due to its velocity and depth. Even supposing that by such a system, under certain peculiar circumstances, it was possible to maintain an entrance channel of a certain capacity, still, at the same time, it would entirely bar all future improvement of the river generally. The bed of the river would inevitably gradually rise by the deposit brought down from the upper reaches of the river by floods or freshes, which could not be removed from the lower reaches without a sufficient tidal volume on the ebb to carry it out to sea. He would advert to some remarks made by Mr. Bateman. One was that the Clyde had been improved more than any other river, and that the dredging had been carried out to an extent unparalleled, and at less cost for labour than in the case of any other river in the United Kingdom. Mr. Abernethy was not prepared to admit that. As regarded the Tyne, the improvements within a comparatively short period had been much greater. It must be borne in mind that the active operations in the Clyde had occupied a period of twenty-eight years, during which 14,000,000 cubic yards of material had been removed by dredging. In the case of the Tyne, in nine years, or less than one-third of the time, 15,000,000 cubic yards had been removed, and there was now a gradually inclined bed from Newcastle to the sea ; the bar which formerly existed was gone, and in all probability would not again be formed. He could not help thinking that there was some truth in Lord Blantyre's statements as to delay.

The Clyde Trustees were about to commence the construction of the Stobcross Dock. Mr. Abernethy recollected visiting the site of that dock twenty years ago, when it was first projected by Mr. Walker. If it was to cost the sum stated, namely, £1,163,000 for a water area of 30 acres, it would certainly be a very expensive and unremunerative dock.

Captain E. K. Calver, R.N., F.R.S., said, the Author introduced his Paper with the following words :—"Probably for no river in the kingdom has so much been done 'by art and man's device' as for the river Clyde, above Port Glasgow." Captain Calver thought, however, there was an exception to that statement to be made in favour of the Tyne. He would give one or two facts in support of that view. In the Clyde, between the years 1837 and 1873, the high water interval between Port Glasgow and Glasgow had been reduced from 1 hr. 23 mins. to 1 hr. 5 mins., a gain in time of 18 mins. in thirty-six years; whereas in the Tyne, between 1860 and 1872, the interval had been shortened between Shields and Newcastle from 1 hr. 3 mins. to 23 mins., or a gain in time of 40 mins. in twelve years. Again, in the Clyde, between 1758 and 1873, an interval of one hundred and fifteen years, the low-water level at Glasgow had been lowered 8 ft.; whereas in the Tyne, from 1860 to 1872, an interval of twelve years only, the level at Newcastle had been lowered 3 ft. 6 in., being now 4 in. below the level of low water at Shields. The points of comparison were 18 miles apart on the Clyde, and 10 miles apart on the Tyne. He brought forward those several facts in order to put in an appearance on behalf of the Tyne, and that credit might be given where credit was due.

It was mentioned in the Paper that Mr. Walker found spring tides at Glasgow to rise 7 ft. or 8 ft., and neap tides at the same place to rise 4 ft.; while at the present time springs rose 10 ft. 6 in., and neaps 9 ft. 3 in.; but those were at periods long after the river was put into a state of improvement. It had been progressively acted upon for one hundred years at least, but no clue whatever was given as to a comparison of the level of high water at Glasgow with the river in its natural state and in its improved state. It was no unusual thing to find that, while lowering the low-water bed by improvement works, the high-water surface was lowered also. Several examples of that might be given, but Captain Calver would only refer to one within his late experience; and that was the case of the Ouse at Lynn. Those present would be aware that the old channel of the Ouse had been forsaken, and that for it had been substituted a cut 3 miles long across Bentinck Marshes, below the town of Lynn. It was originally intended to have a cut 10 miles long, but only 3 miles of it had been carried out. In 1853, while writing a treatise on the conservation and improvement of tidal rivers,[1] and while considering the probable friction of the proposed narrow channel, he predicted that the tide would not rise so

[1] "The Conservation and Improvement of Tidal Rivers, considered principally with reference to their tidal and fluvial powers." 8vo. London, 1853.

high in the upper reaches of the Ouse when the proposed cut was carried out, and that opinion has been sustained by the result. He made a survey of Lynn Deeps in 1871, and he included the rivers to as far as the towns of Lynn and Boston, and to the towers of Wisbeach channel. From the want of reliable data, he had no means of determining how far the high-water level had been affected by the improvement; but, even as far back as 1855, he received information that the tide did not rise so high. He also made it his business five years ago to make further inquiries, and the universal testimony was that the tide did not rise so high as formerly. Though he could not ascertain what was the exact lowering of the surface, he had made some observations which went far to confirm the general fact of reduction in height. In 1871, for instance, in dead neaps, the tide rose 9 ft. 1 in. in Lynn Road, and 9 ft. 5 in. at Lynn Dock, or 4 in. higher at Lynn than it did at the sea; whereas at high springs in Lynn Road it rose 23 ft. 3 in., and at Lynn Dock 22 ft. 5 in., or 10 in. less at Lynn than at the sea. It would, therefore, be perceived that, whereas the high-water level of neaps was 4 in. higher at Lynn than at the sea, the spring high-water level, owing to the short high-water interval, was 10 in. lower; showing clearly that the friction of the narrow cut had a retardative effect in conveying the culminating level of the tide upwards. As a similar effect may have followed on the Clyde from similar works, it was desirable that the Author should supply the Institution with a comparison between the level of high water at Glasgow in the natural state of the river and what it now was. The point was essentially a practical one, and important as well; for, however much the low-water surface might have been lowered for improvement, it was clear that, if the high-water surface was lowered at the same time, it would, to that extent, be a reduction in the whole navigable gain.

Mr. W. A. Brooks said, the last survey of the mouth of the Tyne made by Captain Calver showed a depth of only 17 ft. at low water of spring tides. Mr. Brooks understood Mr. Abernethy to say that the bar was removed. If that was the case it was a happy circumstance; but Mr. Brooks doubted the fact. He would ask Captain Calver to state what was the actual depth, and whether there was no bar?

Captain Calver replied that, he made a survey of the Tyne last year, in preparation for a contest with which the Commissioners were threatened, and he found that there was, literally, no bar, there being a depth of 27 ft. right in from the sea into nearly as far as Shields Narrows. In fact there was deeper

water about the region of the bar than there was in the fair river channel.

Sir JOHN COODE said, it had been critically remarked that the Paper was too historical. To his mind if it had not been historical it would have been nothing; for he failed to see how it would have been possible to convey the facts contained in it without reference to history and dates. The history was like a chain binding the whole of the material facts into one connected whole. The proposition of the late Mr. Rennie, made in 1799, to join up the ends of the several jetties, was the first instance of the adoption of the system of longitudinal training walls, recently carried out with so much success on the Tyne and elsewhere. The Author had remarked that the disappearance of the salmon from the river Clyde was mainly due to the great amount of the traffic; but, above all, he said, to the sewage and other matters poured into the river. With regard to the traffic, Sir John Coode was inclined to question that it had that effect, for he believed he was right in saying in the Tyne the salmon had increased with the river improvements and the remarkable growth of traffic. He mentioned that because, in some rivers, where the value of the salmon fisheries formed an important element of consideration, opposition might be raised to river improvements on the ground of injury to the salmon. Such an opposition had occurred in his own experience, and therefore he should like to know whether it was capable of being shown that the "'whir' of the paddle, the 'churn' of the screw" had exercised an injurious effect upon the salmon in the Clyde? With regard to the sewage, he did not know whether the salmon was a dainty-feeding fish; but at Richmond they might see fishermen congregated in considerable numbers around the sewer outlets; from which it might safely be concluded that there were some fish which certainly did not object to sewage. He thought the disappearance of salmon from this river was principally owing to the deleterious matters discharged into it from the various manufactories on the Clyde.

In his opinion the Appendix to the Paper constituted the most valuable part of the document. There were no less than fifteen tables contained in it, comprising a great amount of valuable practical information. The details as regards the dredging would be more valuable if the Author would furnish the average distance to which the material was conveyed, as also the cost of removing the boulders per cubic yard, and that of the blasting of the rock per cubic yard. Those were facts which Sir John Coode confessed he should like to see introduced, in order that they might be

placed on record. In future operations of that kind, on the rocky portions of beds of rivers, great progress was to be looked for from the use of the steam drill and dynamite, or some one of the other compounds of nitro-glycerine. He had used the steam drill, but not dynamite, because he had been unable to obtain it on account of the stringent restrictions by which its conveyance was surrounded. He considered that they were on the eve of a great change in respect to the cost of submarine blasting operations, and he concurred with the Author that much would hereafter be effected by the use of the drill and by blasting with dynamite. But Sir John Coode would go further, and would say a great deal might, and he believed would, be done without the drill. He had tried experiments with gun-cotton, and he had succeeded in removing 4 tons of hard rock by each 1 lb. of compressed gun-cotton exploded. That would be a good result with drilling, but on the occasion alluded to the gun-cotton was simply placed in canisters upon the surface of the rock, and was exploded with a head of water over it of 8 ft. or 10 ft. He hoped the Author would supplement his Paper by adding a few facts with regard to the cost of the blasting operations on the Clyde.

Mr. J. T. Harrison said, he did not come prepared to take part in the discussion, but he was induced to say a word or two in reference to what had fallen from Mr. Abernethy, who had said the improvement of the river Clyde was a favourable specimen of the effect of giving free action to the tide, for the purpose of scouring and keeping the river clear from shoals. If Mr. Harrison read the Paper rightly, the Author had stated that a great portion of the material dredged was due, not simply to effecting the deepening of the river, but to removing the accumulation which took place in the river after it had been dredged. Mr. Harrison did not find that in the statistics of the Paper any separation had been made of this accumulation from the material excavated for the purpose of deepening. That was rather an important matter in considering the question from the point of view which Lord Blantyre had taken. His lordship stated that, beyond the part so much improved, there was a considerable length of the river over which the tide flowed at comparatively slow velocity. If there was an accumulation of sand there, the effect of the tidal action would be constantly to remove some of that sand, and to deposit it in the upper reach of the river; hence the tidal action would have the effect of constantly silting up the river. If the dredging was discontinued, in course of time the river would return to its former normal condition. This seemed to point to the desirability of improving the river lower down, toward

Dumbarton, where the depth and width required for the navigation were maintained by nature, without any assistance from art, and of removing the materials which the tidal action would carry up the river. Mr. Harrison would be glad if the Author would state what was the quantity of material which the Clyde Trustees had yearly to excavate, in order to maintain the depth which had been obtained. Mr. Harrison had no doubt as to the desirability of deepening, straightening, and confining within river walls or embankments the channel of the Clyde, as described in the Paper, but in his opinion the training walls should be carried above high-water mark; nor did he doubt the advantage of extending the navigable channel above Glasgow Bridge, by the removal of the dam as proposed. Considering the large proportion of deposit to new material dredged out of the Clyde in 1870–71, namely, 345,209 cubic yards deposit, to 558,895 cubic yards of new material—it seemed that very much was required to be done before the Clyde could be considered a satisfactory instance of engineering skill assisting nature to improve a navigable river. The object of the Engineer should be, not merely to form a deep, regular, navigable channel, the result of a large expenditure in rude excavation, and the erection of river walls judiciously directed, but to minimise the deposit in the channel after it was so formed.

There were two sources from which the material forming this deposit might be derived. The first source was the denudation of the river basin, the débris from which was carried down by the river proper during floods. The second source was from sand banks formed at the lower part of the navigable channel—derived partly from the débris from the river basin, and partly, it might be, from the shingle beaches of the adjacent estuary—material from which was carried upward by the tidal action. There was no information given in the Paper as to the relative supply from those sources. Something might be done to arrest the silting up, by trapping the material brought down before it reached the tidal portion of the river, and, if so trapped, it might be removed at probably less cost than it could be dredged from the navigable channel. The river, in its natural state, was just able to carry all the land detritus to the deep water of the estuary. If left to itself, it would gradually silt up and return to its normal condition. He did not think that the tidal river, as improved, was more able to carry detritus to the sea than it was before its improvement was effected; very probably it was less able to do so. At the same time, such works as had been carried out on the Clyde were well calculated to improve the channel in the lower part of the

river, and to deepen the water over the bar, when such an obstruction existed. The sand banks above Dumbarton were essentially similar in character to the Hurd sand at the mouth of the Tyne, and it would be necessary to construct piers to the deep water, or to continue the deep artificial channel to the naturally deep water, before the quantity of material annually dredged was minimised, or the utmost assistance was given to nature by the art of man.

The velocity of the tidal wave was dependent on the depth of water through which it was transmitted—the greater the depth the greater would be the velocity of the wave, or the shorter the interval of time of high water from point to point. But the greater the depth of water, the less also would be the velocity of the water which transmitted a given wave. When the water was very shallow, a bore was formed, as in the Severn and other rivers, and the velocity of the water was nearly as great as that of the wave. He had little doubt but the tidal wave of the Clyde, checked in its progress by the sand banks above Dumbarton, made those sand banks quick, and carried with it a considerable quantity of sand in suspension, and that when the flood tidal water reached the deep-water channel, whilst the velocity of the wave was greatly increased, the velocity of the water transmitting it was much less than it was below, across the sand banks. With such diminished velocity there must be a tendency to deposit the material in suspension some little distance above the shoals, and onward, with an intervening deep. If those views were correct, then there would probably be in the Clyde two points of maximum deposit; one at a short distance below the dam at Glasgow, with an intervening deep, and the other in the part of the channel he had previously suggested.

Mr. Shelford said, the Author had given the observations taken upon one spring tide, when there was no fresh in the river. Those showed that high-water mark reached a level at Glagow 14 in. higher than at Port Glasgow, while the low-water level was about the same at both places. One circumstance had been omitted in the Paper, namely, there was in the upper part of the tidal stream, above Glasgow, a masonry dam across the river—placed there to keep back the fresh water—which prevented the tide from ascending the river channel beyond that point. From his experience and observation, Mr. Shelford considered that dam caused to a great extent, if not entirely, the super-elevation of high-water mark at that part above sea level, and it also accounted for the fact that, when there was no fresh in the river, there was a low level of the low-water mark. He was induced to form that opinion,

because when many years ago he was engaged with Mr. John Fowler, Past-President Inst. C.E., on the Nene, a tidal dam was placed across the river, twelve miles above the mouth, and the effect of that was just what Mr. Shelford had described in the case of the Clyde. The high water was raised by the dam 2 ft. above sea level, and there was a considerable depression of low water. When the dam was subsequently removed, and the tide had free 'swing,' the high-water mark was lowered nearly 2 ft., and the low-water level was considerably elevated, though he could not give the exact amount.

Mr. G. R. Stephenson said, some points had been mentioned which were not in accordance with his views. Having had considerable experience of the Clyde, he had no hesitation in saying that it had been improved more than any other river in the country. He agreed that great credit was due to the Trustees and Engineers who, from time to time, had had charge of the improvements. They had converted it from a ditch into a magnificent channel which would admit any sized vessels trading in Great Britain. Ironclads of the largest calibre and merchant ships of the largest class had been built and launched from its banks. Persons going there at the present time would see ships passing each other at nearly full speed, with ample depth of water, where, twenty years ago, the river was only 1 ft. or 2 ft. deep. He therefore maintained that no river in this country had been so well dealt with or so much improved as the Clyde.

In his comparisons between the Tyne and the Clyde, Captain Calver had forgotten one point: he had omitted to state that it was a much easier matter to convey the sea level 9 miles inland, as in the case of the Tyne, than to take it 25 miles or 30 miles inland, as in the case of the Clyde. With regard to the Tyne, Mr. Stephenson had no hesitation in saying its engineering treatment had been one of the greatest mistakes ever made upon any river in Great Britain. He would briefly state his reasons for that assertion, and in illustration would refer to certain circumstances connected with the river Nene. Many years ago, he recollected a gentleman came to him and asked him to take charge of some works for the improvement of the upland section of that river. The works were a few miles below Northampton, and they had been undertaken with the object of draining that part of the country. Having heard the views of the projectors, Mr. Stephenson expressed his opinion "that it would be best to begin below before they attempted to throw the flood land water towards Wisbeach, where the river was very contracted; and that, if the works were begun above that town—

as they wanted to do—Wisbeach Harbour and its shipping might be washed away by land floods." The period to which he referred was long before the improvement of the lower Nene had been attempted. As he found they did not wish the necessary works to be executed in the lower portion of the river, the matter rested in abeyance. Some years afterwards the work of improving the river was commenced at Wisbeach and carried upwards, and the upland improvement had also been executed. It had proved beneficial both to drainage and navigation.

The mode of dealing with the Tyne was wrong, inasmuch as the works had been begun above the stricture at 'The Narrows,' and consequently a sufficient volume of tide could not be got up the river to keep it scoured; hence the great cost for dredging. With regard to Lynn, he did not know whether Captain Calver meant that the new cut was a success or a failure; because, if regarded as a failure, it was inconsistent with the facts. The late Mr. Robert Stephenson, Past-President Inst. C.E., and himself were the responsible engineers of that work; and during the time he was there—which was from the commencement to the conclusion—the sea level of high water was brought to Lynn, the low-water level was lowered 6 ft., and the bed of the river deepened, so that vessels floated there at low water, with about 12 ft. of water under them. Previously to that work being carried out vessels grounded in the harbour. It was an admitted fact that the works at Lynn to which he referred had been one of the greatest successes obtained in a fen country.

With reference to the bar at Shields, so long as the dredging was kept up the bar would be kept under. In his remarks on the Tyne, Captain Calver had not mentioned 'The Narrows.' Mr. Stephenson would say that was one of the great mistakes in the Tyne. There were, in fact, two great mistakes. The first was the sea-walls or piers. The second was in the order of beginning the work above 'The Narrows.' The Tyne authorities had been spending enormous sums in dredging the channel, to contain a volume of water which could not be got up the river. He meant that, so long as 'The Narrows' existed, the tidal flow could not get up the river to fill the channel. The improvement should have been commenced at 'The Narrows,' and the channel widened upwards. Sea-walls or piers had been built at the sea, and what was called a 'harbour of refuge' had been made, but it might more correctly be termed a 'harbour of destruction,' for it had its opening to the strongest winds that came from the sea. So long as those walls existed so long would that fault remain; and, further, the dredging would always have to be continued, as the river would never maintain itself.

Mr. R. C. Rapier wished to ask the Author his opinion with regard to the weir above Glasgow Bridge. The Clyde authorities by retaining it were preventing the tide rising in the river above it. They were thus shutting up a large tidal area and, consequently, losing a volume of water, which might have swept out the river, at every ebb and flow of the tide. Mr. Rapier had had that point brought before his notice lately with reference to the Orwell at Ipswich—a magnificent estuary, for which nature had done everything, and man had done very little. The greatest facilities existed for increasing its very modest depth of 18 ft. to 24 ft., and that was the utmost he thought could be obtained. Mr. J. F. Bateman, V.P. Inst. C.E., in a report on that subject, had taken into consideration the probable loss of the tidal water which would result from shutting off what was called the 'upper river' at a point where the estuary ceased. Part of the project was to use the 'upper river' as a feeder to keep the upper dock full. The area proposed to be cut off from tidal influence was little as compared with that of the whole estuary. As regarded the dam on the Clyde, Mr. Rapier would ask the Author what amount of water area there was above the dam, and whether the level of Glasgow Green was sufficiently above that part of the river to be secure from inundation from high tides—and what would be the probable additional tidal area there if that dam were removed? If that area was great, the increased scour of the river by the natural efflux and reflux of the tide would be greatly better than the occasional watershed of a heavy rain. Mr. Rapier would add, that Hydronomical Engineers had an immense field before them. Within a recent period, he had had brought prominently to his notice the fact, that several of the magnificent rivers of China required but a small expenditure to obtain the most splendid results from their great natural capabilities.

Mr. D. T. Fender, through the Secretary, said that, having been employed under Mr. J. G. C. C. Godsman, M. Inst. C.E., in observing and discussing the levels, tides, and soundings of the estuary of the river Nene, he had been led to consider the failure of recent attempts to improve the upper portion of that estuary, as a striking example of the necessity which existed for maintaining a proper and symmetrical co-relation between the form of the upper and lower portions of any tidal estuary, or channel proposed to be improved. General investigations as regarded other tidal rivers had also induced him to believe that any abnormal depth for the convenience of navigation or for the berthage of shipping could only be maintained by a costly expenditure for excavation.

The progressive development of the derivative tidal wave of the Clyde presented certain features of interest to the Hydronomical Engineer. Entering the Irish Channel between Rathlin Island and the Mull of Cantyre, the tidal wave turned round the Mull toward Ailsa Craig, thence up the Firth of Clyde to the Cumbray Islands, where it divided into two main branches, one flowing in conjunction with the tidal stream eastward of the Island of Arran up Loch Fyne, the other continuing its course past the Cumbray Islands toward Cloch Point, where it again subdivided, turning eastward up the estuary of the Clyde and northward up Loch Long. At the Mull of Cantyre the range of ordinary spring tides was 4 ft.; at the Cumbray Islands, it was 10 ft., and at Greenock, it was $9\frac{3}{4}$ ft. In Loch Long the range was 12 ft., and at Inverary (Loch Fyne), it was 10 ft.[1] The velocity of the tidal wave, to the Cumbray Islands, was about 55 miles per hour, and from thence to Greenock, 70 miles per hour. To Inverary it was at least 70 miles per hour; and measuring the distance round the western side of the Island of Arran—that being the direction of the main stream—it was 80 miles per hour. The mean velocity in the upper portion of Loch Fyne between East Loch Tarbert and Inverary was increased to more than three times that rate, or to about 250 miles per hour.

He had bestowed much study upon the question "as to the best theoretical form for the self-conservation of a tidal channel," and he believed it to be that in which the cross-sectional area uniformly decreased in the inverse ratio of the square of the distance from the tidal mouth or entrance. In estuaries approximating to that shape, if a capacity diagram was constructed, in which the several cross-sectional areas were represented by ordinates, and the respective distances by abscissæ, it would be found that the outline of the curve joining the ordinates would resemble a half-parabola. Where that form of channel existed, there was uniformity of development both in the flux and reflux of the tidal wave.

The entrance section or mouth of the tidal channel of the Clyde might be described to be between Garvel Point, about a mile above Greenock, and the southernmost point of Ardmore Head, and its natural termination—under existing conditions—somewhere about the west end of Newshot Isle. From thence to Glasgow the river might be considered as a tidal canal. It was therefore below the west end of Newshot Isle that the form of channel he had alluded to as theoretically the best might be expected to be found. To

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[1] "Tide Tables for the British and Irish Ports, for the year 1873." Published by order of the Lords Commissioners of the Admiralty. Page 151.

ascertain how far such a form existed, he had plotted a few cross sections from the Admiralty charts,[1] and had compiled an approximate capacity diagram. At the entrance the sectional area was about 17,000 square yards at high water, ordinary springs. At the west end of Newshot Isle, the sectional area was 800 square yards, also at high water, ordinary springs. At Dumbarton rock, situated nearly midway between those two sections, there was a cross-sectional area of about 4,400 square yards at high water, ordinary springs. The sectional areas at other points along the channel were also nearly in inverse ratio to the square of the distance from the tidal entrance. So far as the capacity of that portion of the Clyde at high water was concerned—and excepting the irregularity of cross-sectional profile occasioned by the parallel dykes—its channel might be considered to be in a fair condition for the rapid flux and reflux of the tidal wave.

From the tide observations furnished by the Author, it appeared that high water traveled from Port Glasgow to Garmoyle Light at a velocity of little more than 11 miles per hour. Between Garmoyle Light and Dumbuck Light the velocity was increased to 24 miles per hour; and between Dumbuck Light and Bowling to $78\frac{3}{4}$ miles per hour. Between Bowling and Dalmuir the velocity was suddenly reduced to about $6\frac{3}{4}$ miles per hour; thence to Renfrew the wave traveled at the rate of 30 miles per hour, and from Renfrew to Glasgow at the rate of nearly 26 miles per hour. The mean velocity with which high water traveled from Port Glasgow to Glasgow was only a little more than 16 miles per hour. Mr. Fender had previously stated that seaward of Greenock, the velocity was about 70 miles per hour. The reduction of the rate to less than a fourth of that velocity would indicate the retardative effect of the sand banks and other obstructions to the free tidal flow. The remarkable increase in the velocity between Port Glasgow and Bowling afforded an example of the general law of increase of velocity in the upper portions of tapering estuaries. It might be worth while to draw attention to the fact that that increase was closely in proportion to the square of the distances of the several stations above Port Glasgow. The observations further showed that between Port Glasgow and Garmoyle Light the velocities at quarter-flood, half-flood, and three-quarter-flood, were respectively 22 miles, 13·4 miles, and 10·3 miles per hour. While thus there was a decrease of velocity towards high water between those two stations, there was an increase of from 5·5 miles to 6 miles to

[1] These charts are partly corrected to 1871.—D. T. F.

7·7 miles per hour between Garmoyle Light and Dumbuck Light, at quarter-flood, half-flood, and three-quarter-flood respectively, and from 5·5 miles to 8·9 miles to 20·9 miles per hour between Dumbuck Light and Bowling at the same times. It was also deserving of notice that half-flood occurred at Glasgow about 20 mins. before it did at Renfrew.

The general conclusions which might be drawn from the previously stated facts were as follows :—1, that not only was there a tendency to augment the range but also to increase the velocity with which high water traveled along the upper portions of gradually tapering estuaries; 2, that when the bed of the channel was very steep, and the narrowing took place rapidly, that increase of range and velocity might be rather attributed to the reduplication of the tidal wave from obstructed momentum, than from any suitability of the configuration of the channel for its upward propagation; 3, that the more nearly the gradual lessening of the cross-sectional area approached to an uniform curve the greater would be the possible range and the actual velocity.

It was usually found that when the form of an estuary decreased uniformly in sectional area from its entrance to its tidal limit, a line joining the summit level of the successive high waters would slope seawards; that where obstructions existed suddenly diminishing the sectional area, that slope would be diminished above the obstructions; until, in extreme cases—as that of the Nene—a considerable landward inclination might take place. Such, he believed, would, to a certain extent, be the case in the Clyde were it not for the existence of the weir at Glasgow. At present it was probable that it heaped up the tidal water, and thus augmented the range of tide in its immediate vicinity. If he was correct in that surmise, its removal, in the present state of the channel below Bowling, would probably occasion a depression of the high-water level in the harbour of Glasgow.

Mr. Deas, in reply, said, he thought he could explain in a few words how the allegations which had been made by Lord Blantyre had been brought about. His lordship was very desirous that, instead of the dredgings being carried out to sea, which was done at a cost of 5½*d.* per cubic yard, they should be put upon his land, at a cost to the Clyde Trustees varying from 10*d.* to 1*s.* 6*d.* per cubic yard. The Trustees very wisely resolved to continue to carry the material out to sea instead of putting it upon his lordship's land. Lord Blantyre then took legal proceedings to enforce his request. The case came before the Court of Session, who decided in favour of the Trustees. Lord

Blantyre appealed to the House of Lords, where he was again unsuccessful in securing legal support to his demand, and that circumstance, to a certain extent, accounted for his lordship's communication to the Institution. With reference to the remark that the portion of the river referred to was not so well improved as it was higher up, to a certain extent that was true; but the stream was much larger and much deeper there than it was higher up, and the object the Trustees had in view was to get it as deep high up as they possibly could—in fact it would be better if it was deeper at Glasgow than it was in the vicinity of his lordship's property, in consequence of the difference in time of tide. Another difficulty there, was a hard patch of gravel concreted together which was very tedious to dredge.

With reference to the remarks of Captain Calver as to the acceleration of tide on the Tyne as compared with the Clyde, Mr. Deas thought Mr. Robert Stephenson's observations had disposed of them. The Clyde was really a hundred years ago a ditch. He did not know that the Tyne was ever a ditch six miles above the sea, but Glasgow was twenty-two miles from deep water.

With regard to the Stobcross Docks, on which some reflections had been made, he had mentioned in his Paper the reasons why those docks were only now being carried out. Until very lately the Trustees were able to obtain ground along both margins of the river for quay extension, and the river was a dock made to their hands. It was only when that ground was exhausted that they turned their attention to making docks out of dry land.

Reference had been made by Sir John Coode to the cost of conveying the dredged material by punts. Mr. Deas would state that the cost of conveyance was so small an item in the total cost of dredging that it was scarcely appreciable. In Table XI. of the Appendix he had given the detailed cost of towing the punts by tug steamer. In 1870–71 there were three places to which the material was carried, and the cost of towing was 2·88*d.*, 1·76*d.*, and 2·34*d.* per cubic yard. The distance which the material was conveyed did not much affect the cost. In some cases the distance the material was carried was 1 mile to 2 miles, in others 7 miles to 8 miles. None of it was taken 27 miles; 6 miles would be a fair average distance.

With regard to the remarks which had been made about the weir at Glasgow, it would be satisfactory, no doubt, to the Members to be informed that it was doomed, and the Clyde Trustees were only waiting for a supply of water to be brought from a higher

reach of the river—for the use of those manufacturers who at present pumped their supplies direct from the river immediately above the weir—to have it removed. He might remark that it was maintained for the water supply of Glasgow before the present supply was brought to Glasgow by the works designed by Mr. Bateman. In fact, the Trustees had a Bill at present before Parliament to get the time within which the weir must be removed fixed at not exceeding four years. By that time it was hoped it would be removed, and that the Clyde would have the benefit of the additional tidal water, which would wash down the river, and add to its velocity.

As to the comparative quantity of deposit and new material dredged, it was stated in the Paper that it varied from year to year. The rainy weather of last year brought down a very large amount of deposit, and it was easily distinguished by the masters of the dredgers from new material. Last year the total quantity dredged was 992,354 cubic yards, of which 300,000 cubic yards were considered to be deposit from the higher reaches of the river and from the city sewers. With regard to the Tyne, he complimented its Engineer, Mr. J. F. Ure, M. Inst. C.E., on the amount of dredging done in that river. They were enabled to excavate more, but there were not the same interruptions to the work that there were in the narrower channel of the Clyde.

In answer to questions as regarded the successive levels of the flood, and of the ebb, of the spring tide of the 11th of April, 1872—given in the tidal diagrams (Plates 22 and 23), and in Table I. of the Appendix—Mr. Deas stated that, previously to the tide observations being made from which the diagrams and tables were compiled, the levels of the zeros of the tide gauges had been determined by a careful series of levels which could be depended upon as correct. The relative depression of the successive surface levels of the ebb tide at the Renfrew gauge—as shown by the diagram (Plate 23)—agreed with the tide observer's book, and the gauge had since been checked with the Ordnance bench mark, and found to be in accordance with the diagram. Mr. Deas had no means of connecting the tide observations taken under his orders with those which had been formerly observed under the directions of Mr. J. Scott Russell, M. Inst. C.E.

The following computations—from the data given in the Appendix[1]—showed the velocity of the tide in the different portions of the river on the 11th of April, 1872; and they might be con-

[1] *Vide* ante, p. 154.

trasted with the computations of the tidal velocity which had been previously given by Lord Blantyre and Mr. D. T. Fender :—

| | h. m. |
|---|---|
| High water at Port Glasgow . . . . . | 2 35 |
| „ „ at Garmoyle . . . . . | 2 55 |
| Tide rose about $3\frac{3}{4}$ miles in . . . | 0 20 |

or at the rate of $11\frac{1}{4}$ miles per hour.

| | |
|---|---|
| High water at Garmoyle . . . . . | 2 55 |
| „ „ at Dumbuck . . . . . | 3 00 |
| Tide rose about 2 miles in . . . . | 0 05 |

or at the rate of 24 miles per hour.

| | |
|---|---|
| High wafer at Dumbuck . . . . . | 3 00 |
| „ „ at Bowling . . . . . | 3 02 |
| Tide rose about $2\frac{1}{2}$ miles in . . . . | 0 02 |

or at the rate of 70 miles per hour.

| | |
|---|---|
| High water at Bowling . . . . . | 3 02 |
| „ „ at Dalmuir . . . . . | 3 25 |
| Tide rose about $2\frac{1}{2}$ miles in . . . . | 0 23 |

or at the rate of $6\frac{1}{2}$ miles per hour.

| | |
|---|---|
| High water at Dalmuir . . . . . | 3 25 |
| „ „ at Renfrew Ferry . . . . . | 3 30 |
| Tide rose about $2\frac{1}{2}$ miles in . . . | 0 05 |

or at the rate of 30 miles per hour.

| | |
|---|---|
| High water at Renfrew Ferry . . . . . | 3 30 |
| „ „ at Glasgow . . . . . | 3 40 |
| Tide rose about $4\frac{1}{4}$ miles in . . . . | 0 10 |

or at the rate of $25\frac{1}{2}$ miles per hour.

| | |
|---|---|
| High water at Port Glasgow . . . . . | 2 35 |
| „ „ at Glasgow . . . . . | 3 40 |
| Tide rose about $17\frac{1}{2}$ miles in . . . | 1 05 |

or at the rate of 16·15 miles per hour.

On the 10th of September, 1835, according to observations made by Mr. Logan :—

| | h. m. |
|---|---|
| High water at Port Glasgow was at . . . . | 2 02 |
| „ „ at Garmoyle . . . . . | 2 30 |
| Tide rose about $3\frac{3}{4}$ miles in . . . | 0 28 |

or at the rate of 8 miles per hour.

| | |
|---|---|
| High water at Garmoyle . . . . . | 2 30 |
| „ „ at Bowling . . . . . | 2 43 |
| Tide rose $4\frac{1}{2}$ miles in . . . . . | 0 13 |

or at the rate of $41\frac{1}{2}$ miles per hour.

| | |
|---|---|
| High water at Bowling . . . . . | 2 43 |
| „ „ at Renfrew Ferry . . . . . | 3 12 |
| Tide rose 5 miles in . . . . . | 0 29 |

or at the rate of $10\frac{1}{3}$ miles per hour.

| | |
|---|---|
| High water at Renfrew Ferry . . . . . | 3 12 |
| „ „ at the Broomielaw . . . . . | 3 50 |
| Tide rose 5 miles in . . . . . | 0 38 |

or at the rate of 7·9 miles per hour.

| | |
|---|---|
| High water at Port Glasgow . . . . . | 2 02 |
| „ „ at the Broomielaw . . . . . | 3 50 |
| Tide rose $18\frac{1}{4}$ miles in . . . . . | 1 48 |

or at the rate of 10·14 miles per hour.

The longitudinal section (Plate 20) would supply the means of comparison between the high water level at Glasgow before and since the river had been improved. It had been prepared from the most reliable data that Mr. Deas could obtain in the archives of the Clyde Trust, and the portion of it relating to the last thirty-five years might be thoroughly depended upon.

Since the Paper had been prepared, a series of cross sections had been carefully taken under his direction—at intervals of about 400 ft. apart—from Port Glasgow to Glasgow. The datum line of those cross sections had been fixed by levelings carried along both banks

of the river continuously from Glasgow Bridge to Port Glasgow, and those levelings had been verified on all the Ordnance bench marks within reach. The following sectional areas in square feet at different points in the river, which had been prepared from those cross sections, would show clearly the character of the channel, and help to illustrate—and it might be to qualify—several of the remarks made in the course of the discussion :—

SECTIONAL AREAS.

| Distance in Miles from Glasgow Bridge. | Area in Square Feet at Low Water. | Area in Square Feet at High Water. | Distance in Miles from Glasgow Bridge. | Area in Square Feet at Low Water. | Area in Square Feet at High Water. |
|---|---|---|---|---|---|
| 3 | 3,900 | 7,500 | 9 | 7,700 | 14,300 |
| 4 | 3,900 | 7,500 | 10 | 5,900 | 16,700 |
| 5 | 4,200 | 8,000 | 11 | 5,600 | 17,200 |
| 6 | 4,300 | 8,200 | 12 | 5,300 | 22,600 |
| 7 | 4,700 | 9,400 | 13 | 7,300 | 35,400 |
| 8 | 6,900 | 14,200 | 14 | 10,700 | 55,000 |

The distance in miles from Glasgow Bridge was shown in Plate 19. At Dumbarton Castle, 14 miles from Glasgow, the narrow channel might be said to terminate, and the estuary of the Clyde to commence.

In answer to the inquiry of Sir John Coode, Mr. Deas stated that he had no data as to the cost of removing boulders. Searching for them by sweeping and by diving-bell occupied much time—varying according to the strata in which they were found—and the time occupied in lifting and disposing of them varied also so much according to the localities in which they were found, that any data that he could give on that point would be apt to be fallacious. Not much rock had been removed since he had entered upon the charge of the works. His immediate predecessor, Mr. Duncan, had given the cost as 44*s.* per cubic yard.

In reply to Mr. J. T. Harrison, Mr. Deas stated that all the training walls lately constructed had been carried several feet above high water mark, and in answer to the questions which had been put by Members in reference to the weir across the river above the harbour of Glasgow, he would state that the height of the crest of the weir was about 2 ft. below average high water of spring tides, and when the river was unaffected by freshes, the depth of water passing over the coping was about 11 in.

From observations made in 1865, by Messrs. Leslie and Duncan, during equinoctial spring tides—with the weather calm, and the river unaffected by freshes—it appeared that the tide rose 2 ft. 10 in. above the cope of the weir, and it was found that the level of the water was raised or affected as far as Eastfield Dye Works, about $4\frac{1}{3}$ miles above the weir; high water there occurring at 4 h. 15 m. P.M. The high water of the same tide in the harbour of Glasgow was at 3 h. 10 m. P.M.; and high water rose 18 in. higher at the Eastfield Dye Works than in the harbour. The average of the lowest neap tides rose to about 12 in. above the crest of the weir.

In a report "On the proposed removal of the weir," presented to the Clyde Trustees on the 24th of February, 1865, by Messrs. Leslie and Duncan, they stated that by measurements of cross sections of the river above the weir taken under their directions, the probable quantity of additional water that would pass up and down each tide, were the weir removed, would amount to rather less than 15,000,000 cubic feet—a quantity equivalent to an area of 42 acres covered with 8 ft. depth of water, that being the average rise of the tide in the harbour at that period. They further stated that that additional tidal water would be obtained with the river bed as it then existed, and that the quantity would go on increasing as the bed deepened and the low water level fell. The level of Glasgow Green was sufficiently high to be secure against inundations from high tides.

May 13, 1873.

T. HAWKSLEY, President,

in the Chair.

No. 1,367.—"On the Changes that have recently taken place along the Sea Coast of the Delta of the Danube, and on the Consolidation of the Provisional Works at the Sulina Mouth." By Sir CHARLES AUGUSTUS HARTLEY, M. Inst. C.E., F.R.S.E.[1]

ON March 11, 1862, a Paper by the Author was read at this Institution entitled "Description of the Delta of the Danube, and of the Works, recently executed, at the Sulina Mouth."[2] That Paper contained an account of the provisional works executed at the Sulina Mouth, and at the conclusion of its discussion a hope was expressed by the President, "that the results of any future works would be communicated to the Institution."

It has appeared to the Author that the time has now arrived when this suggestion may be usefully carried out. In the present Paper, he purposes to give an account of the consolidation of the provisional piers; to describe the mutations of the Sulina Bar from 1861, to the present time; and to refer to the changes that have taken place in the sea outline of the delta during the period of sixteen years that he has served the European Commission of the Danube as their Engineer-in-Chief.

## CONSOLIDATION OF THE PROVISIONAL PIERS.

It may be remembered that the provisional works at the Sulina mouth were undertaken, in 1858, with a view of giving an increased depth of at least 2 ft. for from 6 years to 8 years; and that this duration of time was based on the assumption that during such an interval either the St. George's branch would be opened, or it might be considered expedient to render permanent the provisional works already executed at Sulina. The retention of the Sulina

[1] The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xxi., p. 277.

branch as the sole navigable branch was finally decided on when it was found that the piers at its mouth had maintained an additional depth on the bar of from 6 ft. to 8 ft. for 5 years after their completion, and that sufficient funds could not by any possibility be obtained for the improvement of the St. George. And accordingly, in 1866, the Commission adopted the Author's project for the conversion of the Sulina piers into solid structures. The consolidation works were begun in that year; but little progress was made until 1868, when the Commission, principally through the unwearied exertions of Colonel J. Stokes, C.B., R.E., the British Commissioner in the Commission from 1856 to 1871, raised a loan, on favourable terms, for the completion and extension of the works of improvement at the mouth and in the branch of the Sulina.

These works were then prosecuted with vigour and were brought to completion in the autumn of 1871. The construction of the provisional piers has already been fully described in the Author's first Paper. It will be seen that they consisted of three rows of piles, and that the outermost rows—that is, the northernmost row in the north pier and the southernmost row in the south pier—were of close piling, on either side of which, stones of less than a cubic foot in size were thrown down from barges, and allowed to take their own slope up to the water line. It should also be recalled to mind that the main piles supported a platform of planking 4 ft. above the sea level, and that the timber framing, which consisted of double longitudinal walings and double crossties, was ultimately strengthened by driving a fender pile to the right and left of every bay of the main piles along the whole length of the piers.

During the five years which succeeded the completion of the provisional works, the beat of the waves persistently broke down the ridge of stone work to the level of from 3 ft. to 4 ft. below the water line, but at this depth, except near to the pier heads, the top of the rock work remained intact, even during the most violent gales, as soon as its sea slope and inner slope had been reduced to $2\frac{1}{2}$ to 1, and $1\frac{1}{2}$ to 1, respectively. When the consolidation of the piers was decided on, the problem that had to be solved was, therefore, how best to build in an open seaway a solid wall of $1\frac{1}{4}$ mile in length, 10 ft. thick, and of nearly the same height, from an irregular foundation of 'pierre perdue' up to the level of the fast rotting timber superstructure which the solid wall was meant to replace?

The great irregularity of the bottom, the difficulty of establish-

ing an uniform level on the wave-packed stones—which in many places were jammed so closely together as to require the power of gunpowder to disunite them—and the absence of divers to execute the work, induced the Author, at first, to adopt the plan of building the wall on a roughly leveled foundation, by carefully lowering down masses of unset concrete, within movable timber dams fitted in lengths of from 15 ft. to 30 ft., to the framework of the piers. This plan was not adopted on a large scale until it had been found by repeated experiments that concrete, when made with a sufficient quantity of Portland cement, set perfectly hard on a rocky foundation in a seaway, although lowered through the water in a semi-liquid state. The first trials were unfortunate. Although a distance of 177 ft. from the shore end of the north pier was successfully completed in the manner described before the termination of the year 1866, six blocks, out of the eight 35-ton blocks built at the same time on the rock work near to the pier head, succumbed to the first heavy gales which followed their construction, notwithstanding the care with which the protecting dams had been made, and the precautions taken against the wash of the sea, by nailing a 4-ft. width of canvas to the inside of the vertical planking forming the dam at 2 ft. above the stone work, so that half of the canvas might rest on the foundation and be kept in its place by large stones.

This want of success, in the most exposed part of the pier, caused the Author to conclude, either that the proportion of the cement that had been mixed with sand and gravel—namely, 1 to 4—was not sufficient to insure the stability of blocks composed of concrete which had to set under water, or that isolated blocks thus made in a seaway, and however composed, could not be relied upon. To settle the question it was then determined to try the effect of a winter's gales on twelve isolated trial blocks of a volume of 1 cubic mètre each, composed differently, but all made on the line of works, under the same conditions as the larger blocks which had failed.

Of the twelve trial blocks, which had all been made on the same day, in 1866, in bottomless cases 3 ft. 4 in. high, sunk in 6 ft. of water near to the root end of the north pier, four blocks were not to be found in April, 1867, five months after their immersion; but an examination of the remaining eight blocks, when raised above water and reversed for the purpose of minute inspection, was very satisfactory, for it was proved that the four missing blocks had all been composed of from 1 of cement to from $4\frac{1}{2}$ of sand and gravel, to 6 of sand and gravel, and that not one of the blocks that had

weathered the winter gales was composed of a less proportion of cement to sand and gravel than 1 to 4. It was, moreover, apparent that the hardness of the blocks was in direct proportion to the quantity of cement which had been employed in their construction. As an illustration of this, it may be stated that it was with difficulty that part of the old rock work, which had embedded itself in the concrete when in a plastic state, could be detached with a hammer from the blocks composed of 1 of cement to from 2 of sand and gravel to 3 of sand and gravel, whilst the same kind of stones only clung loosely to the blocks composed of weaker proportions of cement, and in two cases, where the proportion was only 1 of cement to 4 of sand and gravel, they could be removed by a slight pressure of the hand.

These early experiments are particularly alluded to, because their result ruled the ultimate cost of the works, and insured their completion by the time, and for the sum, originally estimated. Owing to financial difficulties it was only possible to add a length of 645 ft. of concrete work to the shore length of the north pier, in 1867.

It was not until the spring of 1868, that funds were provided to begin the works in earnest, and to carry out the consolidation of the north pier to a distance of 2,791 ft. from the shore end before the conclusion of the working season. The consolidation of this portion of the pier was entirely of concrete deposited 'in situ,' as described in referring to the blocks which were broken up by the sea in the autumn of 1866, with the important difference, however, that the immersed part of the concrete wall was less exposed to the force of the waves, and was made with a proportion of 1 of cement to only 3 of sand and gravel, whilst the upper part of the wall above water was composed of 1 of cement to 6 of sand, gravel, and stones. Although the progress of the works was satisfactory on the whole, the experience of the year's work towards its close has shown that it would be both hazardous and costly to continue the same system of consolidation further seaward.

The blocks built in October—which had a cube of 22 mètres each, so as to be finished by the workmen in a single day—had been constructed with great difficulty and expense, owing to the almost perpetual wash of the sea, and it then became evident that if the piers were to be finished by the time prescribed, and for the sum estimated, the 'modus operandi,' which had answered so well in comparatively still water, must be abandoned for some other plan where the work was to be carried on in a more exposed position. It was this conviction that induced the Author, in the spring of

1869, to adopt an alternative plan for consolidating the seaward ends of the piers. This plan was to carry up the wall from a foundation on the rock work, carefully leveled by hand, a system which succeeded perfectly, and will now be described.

As experience had shown that, up to the distance of 600 ft. from the pier head, the heaviest seas had never succeeded in displacing the rock work on either side of the close piling below the level of 4 ft. below the water line, this limit was taken as a guidance in preparing the foundations for the next 1,247 ft. of the north pier. In order to carry out the new plan, it was therefore necessary to establish a perfectly level bed at the depth of 5 ft. over a width of 12 ft., on the river side of the sheet piling, and this work was executed with great labour by skillful Russian divers, called to Sulina for the purpose.

To afford greater security to the foundations, four 3-in. oak planks were spiked to the open piling, which formed the inner row of the provisional piers, the lowest plank being fixed at 7 ft. 6 in. below the water line, and the planking itself was ultimately protected by artificial blocks, 8 tons in weight, carefully set by divers on the 'berme' of the river side of the rock work. The foundation being thus prepared, blocks weighing 18 tons each, and composed of 1 of cement to 7 of sand and gravel, which had been made in the meantime on the timber platform of the pier immediately above the site they were to occupy permanently, were lowered to their beds by powerful 'goliaths,' and as each block was 5 ft. wide, and the distance between the quintuple rows of piles, 7 ft. 6 in., it followed, that as a block was lowered at every bay, the interval between them was 2 ft. 6 in. along the line of works.

The blocks were lowered when 10 days old, and were no sooner placed than the spaces between them were filled up with newly made concrete, which, searching its way under the adjacent blocks, and filling in the grooves moulded in their sides expressly to this end, caused the whole mass—held still further together by the centre row of piles—to become ultimately as solid as if it consisted of but a single stone. The upper surface of the monolith so prepared was studded with projecting stones to tie into the superstructure of the concrete above water, which in calm weather was carried up to the level of the platform without difficulty. The coping or crown of the pier thus formed an integral part of the homogeneous mass below.

In 1869, the north pier consolidation was carried out, as described, 3,200 ft. from the shore, and the south pier was consoli-

dated for a length of 699 ft. on the plan adopted for the shore length of the north pier. In this year, also, steam machinery was erected on shore for the construction of blocks weighing from 10 tons to 20 tons each, which were afterwards thrown from pontoons at random on the outer slope of the rock work adjacent to the head of the north pier; for at this part of the work the waves invariably leveled down the ordinary sized 'pierres perdues'—which were deposited up to the water line at the end of every working season, to protect the sheet piling—to a depth varying from 14 ft., at the pier head, to 5 ft., at the distance of 600 ft. towards the shore. It was therefore necessary to protect the rock work near the pier head with exterior blocks as well as interior blocks of such dimensions, and set at such a depth, that they could not be displaced by the heaviest seas.

In 1870, the remaining length of 1,438 ft. of the north pier, inclusive of the pier-head length of 600 ft., was consolidated on the system begun the year before; and on the 5th of November, the fourth-class dioptric light of the new iron lighthouse supplied by Messrs. Simpson & Co., of Grosvenor Road, Pimlico, was lit up for the first time, and the north pier was then considered completed throughout as a permanent work.

The consolidation of the south pier was also completed up to the high-water line in 1870, but its crown work was not finished until the summer of the following year.

The proportion of cement used in constructing 'in situ' the first 699 ft. length of the south pier, and in filling up the 2 ft. 6 in. gaps between the blocks which had been lowered into place along the last length of 997 ft., was not so great as the proportion employed on similar work at the north pier, for it was found that in the comparatively smooth water in which the south pier is built a mixture of 1 of cement to 4 of sand and gravel was strong enough to harden under water in 10 days, if well protected from the wash of the sea.

The composition of the concrete used for the crown work at the eastern end of the piers was also different—the superstructure of the last 997 ft. of the south pier being of cement concrete, whereas the superstructure of the last 1,400 ft. of the north pier is of Puzzolana concrete, protected by a 3-in. coating of cement and sand mixed together in equal proportions. Another slight difference in the consolidation of the two piers may also be noticed, namely, that in the south pier the submerged horizontal planking was sometimes omitted, on account of great inequalities in the surface of the rock work, and the foundation of the superstructure

was secured by the substitution of artificial blocks on which the upper tier partly reclined. All the Puzzolana employed was furnished by Signor Carlo Nepoti of Rome, and all the cement by the Wouldham Company and Messrs. Knight, Bevan, and Sturge. The Puzzolana was specified to weigh 1,195 kilogrammes per cubic mètre when in a dry state, and the cement was tested by Grant's machine to resist a tensile strain of 350 lbs. per square inch, after being immersed 7 days in water. It is a good proof of the quality of these materials that, up to the present time, there is no sign of failure in any part of the works where they have been used.

The shore length of the south pier, for a distance of 1,304 ft., having become incorporated with the south bank soon after the provisional works were completed, it was not necessary to do more to this portion of the pier than to renew the timber platform and to pitch in more stones to protect the sheet piling up to the water line.

The total sum expended on the Sulina piers, which have now a length of 8,789 ft.—the north pier measuring 5,332 ft. and the south pier, 3,457 ft.—amounted to £185,352 on the 30th of September, 1871, when the works were entirely finished. This sum comprehends the maintenance of, as well as the first outlay on, the provisional works, and the consolidated works; in fact, every charge save that for engineering superintendence, from 1858 to 1871 inclusive. Full details as to the cost of construction, and of the materials employed, are given in the Appendix.[1]

The total cost of the piers, reckoning their whole length as 8,789 ft., has been £21 per lineal foot, in an average depth of 14 ft. of water. The total cost of the consolidated part of the piers, namely, 6,334 ft. in the aggregate, may be stated as having been £26 per lineal foot, in an average depth of 16 ft., including the cost of the provisional works for the same length.

In 1857, before it was decided to try the effect of temporary works at the Sulina mouth, the lowest 'engineer's estimate' for permanent works was £307,200, and the highest was £384,000. It is certain that no contractor could have been found at that time to execute the works, as then designed, for a lower sum; and although the Commission would have been quite justified in letting the work on such terms if it had been found possible and deemed expedient to execute permanent works of improvement at the Sulina mouth in the early days of its existence, the result has now proved that the circumstances which compelled the carrying out of tentative works in the first instance, and their

[1] *Vide* Appendix, I., II., and III., pp. 221 and 222.

subsequent consolidation in the manner just described, without the intervention of contractors for the whole work, have been the means of bestowing a great boon on the navigation at only one-half the amount estimated in the original projects.

These projects, moreover, were to take nine years to execute, and were only designed to increase the depth on the bar to 16 ft., instead of to 20 ft., the depth that the navigation now enjoys, and the attainment of which the most sanguine never ventured to predict when the works, now completed, were begun. In short, the experience that has been gained by the construction of the Sulina piers has convinced the Author that if, from the beginning of the works, the European Commission of the Danube had chosen the Sulina as the only channel that could be successfully treated with the means at their disposal, it would hardly have been possible to have adopted a better plan than that which has been carried out; that is to say, the construction in the first instance with great rapidity of simple training works of timber and stone, such as the nearest forests and quarries produced, and then consolidation later on with concrete, when the stone work had been beaten down to its ultimate level by the action of the waves.

Before bringing the first part of this Paper to a close, it should be stated that the piles used in the construction and strengthening of the provisional works are as sound at this moment below the water line as when they were driven, and that the stability, as well as the comparatively slight cost of the works as now completed, is mainly due, in the Author's opinion, to the 16,000 piles with which the original work was constructed; and which, apparently, are destined to remain intact for centuries to come.

## State of the Sulina Bar from 1861 to 1872.

The condition of the Sulina mouth before its improvement was undertaken by the Commission, and during the time that the provisional works were in progress, has already been described in the Author's first paper, and therefore reference need only now be made to the changes which have taken place since 1861. It may be well, however, to remark here, for the information of those who are unable to refer to the first paper:—

1. That when the European Commission of the Danube began its labours, in 1856, the entrance to the Sulina branch was a wild open seaboard strewn with wrecks, the hulls and masts of which, sticking out of the submerged sand banks, gave to mariners the only guide where the deepest channel was to be found.

2. That the depth of the channel varied from 7 ft. to 11 ft., and was rarely more than 9 ft.

3. That the site now occupied by wide quays, raised high above flood level and more than 2 miles in length, was then entirely covered with water when the sea rose a few inches above the ordinary level, and that, even in a perfect calm, the banks of the river near the mouth were only indicated by clusters of wretched hovels built on piles, and by narrow patches of sand skirted by tall weeds, the only vegetable product of the vast swamps beyond.

4. That, in the summer of 1857, three months of constant dredging and raking on the bar produced no appreciable effect.

5. That on the completion of the provisional piers in 1861, the depth on the bar increased to 17 ft., and Sulina, instead of being the worst harbour, at once took the highest rank among the best commercial harbours in the Black Sea.

From the completion of the provisional works up to November, 1862, the depth on the bar maintained itself at 17 ft., and it was only in December that the channel began to deteriorate, on account of the feeble current issuing from the river.

This diminution in the velocity of the current being continued throughout the whole of 1863, produced the rapid growth of a bank between the pier heads, so that in October, the depth of the navigable channel had fallen to $15\frac{1}{2}$ ft., and to $13\frac{1}{2}$ ft. in December. In January, 1864, owing to the comparative purity of the river waters, and to the long duration of a westerly wind, the bar channel deepened to $15\frac{3}{4}$ ft., and during the floods of March, April, and May, it became wider, from the same cause. At the beginning of June, however, this progressive improvement was arrested, although the force of the current was not diminished—and it was at this time, when it seemed that the floods had attained their greatest height, that the Author recommended the Commission to prolong the south pier as soon as the bar channel began to fall off again in depth. The reasons he gave in support of this proposal were as follows :—

1. Experience had taught that between the piers the channel had kept itself at the normal width of 580 ft., and at the depth of 17 ft., by the ordinary action of the river current.

2. It had shown also that low summer floods did not produce scour enough to carry away the deposits, formed during low water in the river, beyond the parallelism of the piers.

3. It was also proved that the action of the sea on the bottom, during storms, swept away the banks deposited in calm weather beyond the north pier head.

4. The projection of the sand bank immediately off the south pier head had become so considerable, that the entrance was only very slightly protected by the north pier during the prevailing N.N.E. winds, and thus the extra length of 650 ft. given to the windward pier, beyond the south pier, principally to afford this shelter, was no longer of much use.

5. The sand bank which had thus accumulated was itself as much in the way of vessels entering and leaving the port as a solid work of timber and stone carried from the south pier head to a point directly opposite the north pier head.

It was on a consideration of these facts that the Author first arrived at the opinion that the Commission should hold itself prepared to prolong the south pier about 500 ft., in order that—the overlap of the north pier being reduced to 150 ft.—the river deposits, during a long duration of a feeble river current and of calm weather, might be thrown down well clear of the pier heads, instead of between them as heretofore. Throughout the whole of June, there was no improvement in the channel, but early in July, a second flood, aided by a strong and long continued westerly wind, increased the current across the bar to 3 knots per hour, and almost immediately produced the effect of deepening the channel between the pier heads to 17 ft.; an improvement which maintained itself for the rest of the year. The question of prolonging the south pier was therefore postponed for a time, on the principle that "well should be let alone," a proverb which it is desirable to remember in all questions concerning the improvement of rivers, and more especially of their outlets to the sea.

In 1865, the depth on the bar never fell below 17 ft., and towards the end of the year, it increased to 18 ft. over a width of 400 ft., owing to the effect of high floods in the spring and summer and, as in 1864, owing to the comparative purity of the effluent waters after the floods had subsided. In 1866, on the 7th of April, soundings on the bar gave $17\frac{3}{4}$ ft., whereas on the four following days they fell off to $16\frac{1}{4}$ ft., and on the 12th, to 14 ft. This serious and sudden shallowing of the bar, so unlike its gradual deterioration in the early part of 1864, at a similar season of low water, may be thus accounted for. The meteorological observations, taken at Sulina in April, seemed to prove that the sudden diminution of $2\frac{3}{4}$ ft. in less than a week was produced by winds blowing into the mouth from the east, and across it from the south, at a time when the feeble current issuing from the river was heavily charged with alluvium. Thus it appeared by

the register that, on the 6th of April, the wind was S. and S.E., on the 8th, directly E., and on the 9th, 10th, and 11th, generally from E. to S.; that the greatest velocity of the current during this time was only 112 ft. per minute; and that the amount of matter held in suspension was 156 grains, on an average, per cubic foot of water. On the 14th, the wind changed to N.W.; the suspended matter was reduced to 108 grains per cubic foot; and the channel deepened to 15 ft.—a portion of the newly discharged silt, which was almost in a liquid state, having by this time been removed by the beneficial action of comparatively clear water flowing uninterruptedly in the direction of the littoral current across the mouth. A synopsis of the meteorological observations made daily at Sulina from 1862 to 1871 inclusive, will be found in the Appendix.[1]

Many of the Sulina pilots were of opinion that the deposits, which lodged on the bar on the 11th and 12th, came in from the sea, and consisted chiefly of the roots and 'débris' of reeds. If so, this would at once account for the great variations in the channel between the 11th and 14th; but in the absence of any proof in support of the pilots' theory, the Author maintains his opinion that the primary cause of the shallowing was owing, as on former occasions, to a slack river current unduly surcharged with earthy particles, meeting at its issue from the river with southerly and easterly winds.

On the 25th of April, after a strong gale, of three days' duration, from the N.E., it was found that the new deposits had been carried away, and that the channel had again deepened to 16½ ft. Henceforward, to the end of the year, the depth of the channel was never less than 16½ ft., but its width at this depth was seldom more than 150 ft. Notwithstanding the re-formation of the bank under shelter of the north pier, and the consequent narrowing of the channel between the pier heads, the sand banks off the entrance felt the beneficial influence of the autumnal gales, so that to seaward of the piers the state of the entrance was much better during the three latter months of the year than in the previous spring.

The floods of 1867 improved the bar, but it became necessary in this year to prolong the north pier landwards for a length of 560 ft. —which was afterwards extended to 694 ft.—to keep pace with the erosion of the north shore, and to preserve the continuity of the roadway between the pier and the land. In 1868, the beneficial action of high floods was again felt at the mouth, so that, through-

[1] *Vide* Appendix, IV., p. 223.

out this year, the depth on the bar never fell below 17 ft., and was often as much as 18 ft.

In 1869, as in 1863 and in 1866, there were no river floods, and consequently the south sand bank again advanced in such a way between the pier heads as seriously to deteriorate the channel. In March—when the velocity of the current was reduced to 1 mile per hour, and when the fluvial waters were laden with an unusual amount of alluvium—the depth of the channel alongside the projection of the north pier fell off to 15 ft., and its width to less than 150 ft.; and although it improved somewhat in the month following, its depth throughout the year never exceeded 16 ft., whilst its width at this depth was seldom more than 100 ft.

With a view to remedy this unsatisfactory state of the entrance, it was resolved, in July, to carry out, without further delay, the seaward extension of the south pier, which the Author had recommended five years before, so that the overlap of the north pier being reduced to 150 ft., the fluvial deposits might be thrown down beyond the head of this pier instead of to the south and south-west, under its shelter, as heretofore. By November, the total length of the south pier prolongation, namely, 457 ft., was nearly completed, after the same fashion as that of the provisional piers, but, owing to the absence of floods, the effect of the new work was not apparent until the end of the year.

Early in 1870, however, it was seen that the action of the floods was much more efficacious than usual, owing to the recent extension of the south pier and to the consolidation of the piers near to their extremities. Thus, on the 7th of January, the depth at the mouth was only $16\frac{1}{2}$ ft., whilst, on the 19th of February, it increased to $18\frac{1}{2}$ ft.; on the 19th of March to $20\frac{1}{2}$ ft., and on the 24th of March to 22 ft. Between these last dates the river attained its greatest velocity—$3\frac{1}{2}$ knots per hour. By the end of the year, although the south bank to the seaward of the piers had advanced considerably since the subsidence of the floods, the depth remained at 22 ft. off the entrance in a north-easterly direction, and between the piers where they run parallel to each other; but above this point, where the piers are further apart, the depth of the channel did not exceed 19 ft. over a short distance—so that the profitable depth of the channel was also limited to 19 ft.

In the spring of 1871, the good effects produced by the consolidation of the piers, and by the extension of the south pier, were again shown in a marked manner by the still further deepening of the channel; and although the re-appearance, at this time, of the south bank, far to seaward of the piers, in precisely the same spot

as it occupied ten years previously, again gave rise to apprehensions as to its ultimate advance to the north, it was proved, at the end of the year, as in 1861, under the same circumstances, that this menacing bank—produced at times of extraordinary floods by scour and precipitation combined—gradually disappeared under the salutary action of the subsequent autumnal and winter gales. Thus, in November, the tail of the bank was much further to the south than in the spring, and vessels drawing 19 ft. could then enter and leave the port by a straight and wide channel without being obliged to make a considerable detour to the north, as in the early part of the season.

In 1872, high river floods again prevailed, but being of shorter duration, and less charged with matter held in suspension than the floods of 1871, the improvement produced on the south bank by the winter gales was maintained throughout the year; and as the channel over the short shoal westward of the parallelism of the piers was scoured 1 ft. deeper in the spring, an effective depth of 20 ft. was then signalled to the navigation for the first time from the lighthouse tower.

A few words should now be said relative to the practical results which have followed the deepening of the Sulina mouth from 9 ft. in 1857, to 20 ft. in 1872. In 1853, 2,490 vessels, measuring together 339,457 tons, left the port; in 1869, 2,881 vessels, with 676,960 tons, cleared seawards. The fact that the number of vessels was only 16 per cent. higher, whilst the tonnage had doubled, is significant of the improvement effected; whilst the reduction of the number of wrecks at the Sulina mouth—from an average of 39 in 10,000 leaving the river from 1855 to 1860, to an average of 8 in 10,000 from 1861 to 1869, of 3 in 10,000 for 1869, and of only 2 in 10,000 since—shows the greater security now afforded to shipping. The charges, also, have been notably reduced. In 1857, a vessel paid from 2 francs to 3 francs per quarter for lightening her grain across the bar, whereas the charges a vessel now pays, in the shape of dues for the use of the port, are only 2 francs per register ton, or one-seventh of what she paid formerly, when the Sulina mouth was generally regarded by seafaring men as a cemetery of wrecks.

These results are independent of the increased facilities afforded in the Sulina branch to shipping ascending the river to the great corn exporting ports of Galatz and Ibraila, by the straightening and deepening works executed by the Commission, under the personal direction and on the designs of the Author, whereby the navigable depth in that branch has been increased 5 ft.—by the improvement of eleven of its worst shoals—its length shortened 1 mile, and three

of its most difficult bends avoided by the cutting of an entirely new channel, 20 ft. deep and 230 ft. wide, through the marshy ground of the delta at 24 miles from Sulina. The limits assigned to a single Paper will not admit of more than this brief allusion; but a detailed description of the river works which have been undertaken in the Sulina branch since 1857 will probably be presented to the Institution on a future occasion.

### Recent Changes along the Sea Coast of the Delta.

The Author in his first Paper referred to the Russian Government survey, of 1829, as being the earliest authentic survey of the Sulina bar extant, and he compared it with the Commission surveys of 1857 and 1862, to illustrate some of the changes that had taken place at the Sulina mouth up to the time of the completion of the Sulina provisional works. For the purposes of the present Paper it will be more satisfactory to disregard the period of $4\frac{1}{2}$ years between the spring of 1857 and the autumn of 1861—when the provisional works were under execution, and when consequently the mouth was in an abnormal state—and to confine the following comparison to the term of twenty-eight years previous to the commencement of the piers, and to that of ten years immediately subsequent to their completion:—

1. To the north of the entrance, from 1829 to 1857, the contour lines of soundings of 6 ft., 9 ft., and 12 ft. receded 112 ft. towards the land, or at the rate of 4 ft. per annum, whereas between 1861 and 1871, the same lines receded 1,050 ft., or at the rate of 105 ft. per annum.

2. From 1829 to 1857, the contours of 15 ft. and 18 ft. advanced 1,025 ft. seawards, or $36\frac{1}{2}$ ft. per annum, whereas from 1861 to 1871, the same lines receded 725 ft. towards the land, or at the rate of $72\frac{1}{2}$ ft. per annum.

3. From 1829 to 1857, the contours of 24 ft. and 30 ft. advanced 2,925 ft., or 104 ft. per annum, while from 1861 to 1871, they only advanced 600 ft., or 60 ft. per annum.

4. To the south of the entrance, from 1829 to 1857, the contours of 6 ft., 9 ft., 12 ft., 15 ft., and 18 ft. only advanced 630 ft., or 23 ft. per annum, whilst from 1861 to 1871, the same lines advanced 950 ft., or 95 ft. per annum. From 1829 to 1857, the contour lines of 24 ft. and 30 ft. advanced 2,425 ft., or $86\frac{1}{2}$ ft. per annum, whereas those of 1861 to 1871, only advanced 425 ft., or $42\frac{1}{2}$ ft. per annum.

A consideration of the preceding facts leads to the conclusion that the projection of the piers at the Sulina mouth has had the effect of

greatly deepening the sea bottom to the north of the piers, between the shore and the 18-ft. line of soundings, and of accelerating the shallowing of the sea bottom to the south of the piers over the same depth. On the other hand, the works seem to have had the effect of greatly retarding the growth of the 24-ft. bank and of the 30-ft. bank, as the advance of those banks eastward—to the north and south, and in front of the piers—during the ten years ending November, 1871, was only 44 ft. per annum, whereas during the twenty-eight years immediately previous to the beginning of the works, the same contour lines advanced at the rate of 97 ft. per annum. From this investigation it may be assumed that the piers have hitherto had the effect of diminishing, by more than one-half, the old rate of the advance of the delta at the Sulina mouth as represented by the 24-ft. line and 30-ft. line of soundings; of encouraging the growth of the sand banks directly under the shelter of the south pier; and of causing a rapid erosion of the sea bottom northwards of the north pier along its whole length, an action which has naturally extended itself to the line of shore, thus necessitating, as has already been observed, a prolongation of 694 ft. from the shore end of the pier.

The causes of these phenomena may be briefly explained as follows:—The slower advance of the delta, as limited by the 'tails' of the 24-ft. bank and of the 30-ft. bank, is due to the circumstance that the great bulk of the silt bearing waters of the river on issuing, as at present, at once into deep water beyond the pier heads is, as a rule, carried far to the south-east by the littoral current, instead of flowing into the sea, as formerly, with a feeble and constantly decreasing current, by numerous shallow channels, which were always changing in direction and extent. The increased, but only local, growth of the south sand banks has been mainly occasioned by the shelter afforded to them by the piers from the prevailing winds, and it is clear that immediately behind the south pier this shelter has encouraged a more rapid precipitation of solid matter from the turbid waters which escape laterally and in a south-westerly direction after rounding the south pier head. The remarkable erosion to the north of the piers is probably chiefly due to the rebound of the sea against the north pier during heavy northerly, and north-easterly gales. The inroad of the sea, which was comparatively feeble before the works were constructed, became very much greater when the outflowing river waters were divided from the sea by a solid wall of 1 mile in length; and this is proved by the fact that the 9-ft., 12-ft., 15-ft. and 18-ft. contour lines of soundings of to-day take the place of the 6-ft., 9-ft., 12-ft. and 15-ft. contours respectively of ten years ago.

The foregoing remarks on the changes that have lately taken place at the Sulina mouth are limited to the space comprised between two imaginary parallel lines 5,000 ft. apart, the southern line being drawn due east of the old lighthouse. On extending the investigation beyond this range, and on comparing Captain Spratt's survey of the delta in 1856 with Mr. Hansford's survey made under the Author's direction in 1870, it will be found, as was to be expected, that the changes in the sea bottom have been much greater at the other mouths of the Danube than at Sulina, which, it may be remembered, only delivers two twenty-sevenths of the whole volume of the river to the sea.

Beginning from the north, it will be observed, that opposite the Ochakoff mouth of the Kilia (Plate 24), the 6-ft. line of soundings has advanced 6,000 ft., and the 30-ft. line 5,000 ft., since 1856, or at the rate of 333 ft. per annum.

The enormous growth of the Kilia delta at this point, as compared with its advance during the previous twenty-six years, is due to the greatly augmented volume of water which has lately flowed to the sea by the Ochakoff branch, a phenomenon which fully confirms the remark made by the Author in his first Paper, that the amount of deposit at the various mouths of the Danube was almost directly in proportion to the volume of water issuing from them, and that an increased volume flowing out at any mouth unprovided with training works, had the effect of shallowing that mouth, rather than of deepening it. The latter remark is also confirmed by the fact that while, in 1856, the depth on the Ochakoff bar was 6 ft., it had fallen off to less than 3 ft., in 1871.

Opposite the New Stamboul mouth the advance of the delta has also been greatly accelerated of late years owing to the same cause. A comparison at this point between the Russian survey, of 1830, and the English survey, of 1856, shows that the advance of the 6-ft. line and 30-ft. line of soundings during that period was at the rate of 211 ft. per annum, whilst from 1856 to 1871, when the last Commission survey of the Kilia mouths was made, it appears that the 6-ft. contour line had advanced at the rate of 240 ft. per annum, and the 30-ft. line at the rate of 400 ft. per annum.

To the S.S.E. of the Kilia delta, at the mouth of the old Stamboul branch, near Massurah Point, the 6-ft. line of soundings advanced 1 mile, or at the rate of 230 ft. per annum, and the 30-ft. line, from 1830 to 1856, at the rate of 134 ft. per annum; whilst during the fifteen subsequent years the advance of the 6-ft. line only equalled 200 ft. per annum, and the total advance of the 30-ft. line was reduced to 100 ft., or to 7 ft. per annum. This diminution

in the advance of the southern extremity of the Kilia delta seems clearly to indicate that the impoverishment of the old Stamboul branch by the abstraction of late years of a considerable portion of its waters by the Ochakoff branch and by the New Stamboul branch, has had the effect of encouraging the growth of the sand banks at the mouths of the latter at the expense of the former.

The recent changes from purely natural causes in the relative volumes of water delivered to the sea by the Kilia mouths, may be regarded as a favourable circumstance in considering the problem of the number of years that will elapse before the Sulina mouth is absorbed in the shallows of the Kilia delta. Such a catastrophe would soon be imminent, if all the detritus carried to the sea by the Kilia was deposited immediately adjacent to its numerous mouths; for, according to the Author's calculation, deduced from ten years' regular observation, 426,000,000 tons of solid matter held in suspension in the river waters were discharged into the Black Sea by the Kilia branch from 1862 to 1871 inclusive—a quantity equal to the excavation of three Suez Canals, or to a mound, 20 ft. high, covering 14 square miles of surface. This calculation is based on the Author's gaugings of the Danube in 1857, when he found that seventeen twenty-sevenths of its entire volume escaped by the Kilia branch, eight twenty-sevenths by the St. George's branch, and two twenty-sevenths by the Sulina branch. Since that period, owing to the shallowing of the Toultcha branch and St. George's branch, the outflow by the Kilia has increased, so that it now delivers eighteen twenty-sevenths, or two-thirds, of the whole volume of the Danube to the sea. A synopsis of observations and calculations concerning the discharge of the entire volume of the Danube from 1862 to 1871 inclusive, together with an analysis of the deposits of the Lower Danube, will be found in the Appendix.[1] Fortunately for the Sulina mouth the largest proportion of this vast mass of detritus was transported far to sea, and but little, comparatively, went to swell the shallows off the Kilia mouths. It should be remarked, moreover, that the advance of the latter to the south could at any time be greatly retarded by the partial or complete closing of the Stamboul branch of the Kilia by means of artificial works.

For 4 miles from the edge of the 6-ft. bank off the Old Stamboul mouth to a point situated at about 2 miles to the north of the Sulina piers, the 30-ft. line of soundings has not perceptibly changed its position since 1856. From that time to the year 1871, however,

[1] *Vide* Appendix, V. and VI., pp. 224 and 225.

the same line receded about 1,800 ft. towards the shore at about 4½ miles from the Stamboul bank, and the erosion has been continued to a point less than ½ mile from the piers, whence, for about 1 mile south, directly across the pier heads, the 30-ft. line has advanced at the rate of 40 ft. per annum from 1861 to 1871. At less than ½ mile to the south of the piers the 30-ft. line, of 1870, is again identical with that of 1856, so that it may be said that, from 1856 to 1871, the slight advance of the Sulina delta, as represented by the 30-ft. line of soundings, has been confined to a space of less than 1 mile directly in front of the piers. From a point ½ mile south of the piers the 30-ft. lines are again identical for about 1 mile, but thence, for a length of 7½ miles, the 30-ft. and 6-ft. lines are in some places ½ mile nearer the shore now than in 1856, and the adjacent shore line has been encroached upon in almost the same proportion. At 9 miles from Sulina, the lines of soundings of 30 ft. and 6 ft., of 1856 and 1870, again converge, and thence maintain the same line, or nearly so, for a distance of 7½ miles to the Kedrilles mouth of the St. George, the adjacent shore lines being also nearly the same, except over a distance of 1½ miles from the Kedrilles mouth, where the land has gained about 600 ft. on the sea. Opposite the Kedrilles mouth and thence for 4 miles to the S. and S.S.W., the 30-ft. bank and the 6-ft. bank, from 1856 to 1870, have advanced about 1,800 ft., or at the rate of 128 ft. per annum, notwithstanding the advantages that this mouth possesses over all the other mouths of the Danube, in having much deeper water directly seawards, and a stronger littoral current nearer shore. On the other hand it should be observed, that if the Kedrilles mouth of the St. George's branch had been deepened by means of parallel piers, as proposed by the Author, and as recommended by the Austrian, British, Sardinian, and Turkish Commissioners in 1857, the growth of the 30-ft. bank would probably not have exceeded that of the same line of soundings at Sulina, where, doubtlessly, owing to the projection of the piers, the growth of the delta as represented by that line, is much less than formerly, as has been already pointed out.

This rapid sketch of the changes that have taken place in the sea bottom skirting the delta since the first authentic survey of 1856, shows that, during a period of fifteen years, the advance of the 30-ft. line of soundings has been strictly confined to the sand banks facing the mouths of the Kilia, Sulina, and St. George, and that an erosive action has been long at work on the shore line and sea bottom to the north and south of the Sulina mouth. This degradation of the coast line of a delta is an interesting fact, but

until longer and closer observations have been made, it cannot be altogether satisfactorily accounted for. In pursuing the inquiry, it is unfortunate that the non-existence of any trustworthy surveys of the coast line, previous to 1856, renders it impossible to say how long the erosive action of the sea, now so marked, has been in progress, or what has been the precise effect produced on the coast to the south of Sulina, by the projection at right angles from the shore at the Sulina mouth of what may in one sense be called a single groyne, 1 mile in length.

In this state of uncertainty as to the precise causes which have given rise to the encroachments on the land, and as to the length of time which they have been in operation, it is gratifying to reflect that the inroads caused by the waves and currents on both sides of the Sulina mouth, and the merely local advance of its sand banks seawards, are favourable indications as regards the maintenance of a good navigable channel at the entrance; and it is also a subject of congratulation to find, on the completion of the permanent works at Sulina, and after an experience of fifteen years, that the growth of the Sulina delta to the south and east has fallen short of expectation, and that in this respect it contrasts favourably with what has taken place during the same period at the mouths of the Kilia and the St. George.

The Paper is illustrated by a series of drawings and diagrams, from which Plates 24, 25, 26, 27, and 28, have been compiled.

# APPENDIX.

CONTENTS.

I.—Statement of the Amount expended and of the Materials employed in the Construction and Maintenance of the Sulina Piers, from the 21st of April, 1858, to the 31st of October, 1871, exclusive of their Consolidation.

II.—Details of the Cost of Consolidating the Sulina Piers, from June, 1866, to October, 1871.

III.—Abstract of the Cost of the Sulina Piers, including their Consolidation, from the 21st of April, 1858, to the 30th of September, 1871.

IV.—Synopsis of Meteorological Observations made daily at Sulina from 1862 to 1871 inclusive.

V.—Synopsis of Observations and Calculations concerning the discharge of the entire volume of the Danube from 1862 to 1871 inclusive.

VI.—Analysis of Danube Deposits, by Henry K. Bamber, Esq., F.C.S., London, from specimens sent to him from Galatz and Sulina by the Author.

I.—Statement of the Amount expended and of the Materials employed in the Construction and Maintenance of the Sulina Piers, from the 21st of April, 1858, to the 31st of October, 1871, exclusive of their Consolidation.

| | Materials. | | | Price. | | Totals. | |
|---|---|---|---|---|---|---|---|
| *Construction of the Provisional Piers, from April, 1858, to October, 1861.* | Piles. | Rubble. | Concrete. | | | | |
| North Pier :— | No. | Stingens.[1] | Cubic Mètres. | Francs. | Francs. | Francs. | £. |
| Piles, including the cost of the superstructure | 8,178 | .. | .. | 50 | 408,900 | | |
| Rubble | .. | 11,662 | .. | 90 | 1,049,580 | | |
| Plant | .. | .. | .. | .. | 115,835 | | |
| | | | | | | 1,574,315 | |
| South Pier : – | | | | | | | |
| Piles | 4,202 | .. | .. | 50 | 200,100 | | |
| Rubble | .. | 3,768 | .. | 90 | 339,120 | | |
| Plant | .. | .. | .. | .. | 50,000 | | |
| | | | | | | 589,220 | |
| *Maintenance of the Piers, from 1st of November, 1861, to 30th of September, 1871.* | | | | | | | |
| | | | | | | 2,163,535 | 86,542 |
| North Pier, including a prolongation of 694 ft. :— | | | | | | | |
| Piles | 2,779 | .. | .. | 40 | 111,160 | | |
| Rubble | .. | 2,169 | .. | 90 | 195,210 | | |
| Plant and labour | .. | .. | .. | .. | 501,590 | | |
| | | | | | | 807,960 | |
| South Pier, including a prolongation of 457 ft. :— | | | | | | | |
| Piles | 1,235 | .. | .. | 40 | 49,400 | | |
| Rubble | .. | 2,120 | .. | 90 | 190,800 | | |
| Concrete blocks | .. | .. | 805 | 60 | 48,300 | | |
| Plant and labour | .. | .. | .. | .. | 251,700 | | |
| | | | | | | 540,200 | |
| | | | | | | 1,348,160 | 53,926 |
| | | | | | | | £140,468 |

[1] 1 'Stingen' = 245 English cubic feet.

II.—Details of the Cost of Consolidating the Sulina Piers, from June, 1866, to October, 1871.

| | Concrete. | Price. | Totals. | |
|---|---|---|---|---|
| North Pier. | | | | |
| Length consolidated, 4,638 ft. | Cubic Mètres. | Francs. | Francs. | £. |
| Concrete hardened under water . . . | 4,080 | 84·50 | 344,760 | |
| Concrete blocks made on the pier by hand and by steam power . . . . . | 2,348 | 35·48 | 83,307 | |
| Concrete for the crown work—in cement . | 1,391 | 43·00 | 59,813 | |
| Do. do. —in Puzzolana and cement | 975 | 42·72 | 41,652 | |
| Concrete blocks made on shore, by means of Messart's machine, mounted on a traveling platform and worked by steam . | 3,190 | 33·48 | 10,680 | |
| | 11,984 | .. | 540,212 | |
| Labour—leveling the 'pierres perdues' by divers . . . . . | .. | .. | 105,660 | |
| Transport of materials to the pier. . . | .. | .. | 74,053 | |
| Oak planks—7,368 × 10 in. × 3 in. . at | .. | 0·80 | 5,910 | |
| Plant (steam engines, goliaths, rails, &c.) | .. | .. | 87,000 | |
| Damages caused by gales . . . . . | .. | .. | 12,350 | |
| | | | 825,185 | 33,007 |
| South Pier. | | | | |
| Length consolidated, 1,696 ft. | | | | |
| Concrete hardened under water . . . | 1,754 | 62·00 | 108,748 | |
| Concrete blocks made on pier . . . . | 1,096 | 35·48 | 38,886 | |
| Concrete for crown work—in cement . . | 1,004 | 43·00 | 43,172 | |
| | 3,854 | | 190,806 | |
| Labour—leveling the 'pierres perdues' by divers . . . . . | .. | .. | 32,100 | |
| Transport of materials to the pier. . . | .. | .. | 27,151 | |
| Oak planks—3,576 × 10 in. × 3 in. . at | .. | 0·80 | 2,861 | |
| Plant . . . . . | .. | .. | 38,000 | |
| Damages caused by gales . . . . . | .. | .. | 6,000 | |
| | | | 296,918 | 11,877 |
| | | | | £44,884 |

III.—Abstract of the Cost of the Sulina Piers, including their Consolidation, from the 21st of April, 1858, to the 30th of September, 1871.

| | £. |
|---|---|
| Provisional Works . . . . . | 86,542 |
| Maintenance and Prolongations . . . . . | 53,926 |
| | 140,468 |
| Consolidation . . . . . | 44,884 |
| Total . . . . . | £185,352 |

IV.—Synopsis of Meteorological Observations made daily at Sulina from 1862 to 1871 inclusive.

| Year. | Direction of Wind. Percentage. | | | | | Barometer at 32° Fahrenheit at sea level. | | Thermometer in the shade. | | Rainfall. | River closed by Ice. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | N. to E. by N. | E. to S. by E. | S. to W. by S. | W. to N. by W. | Calm. | Max. | Min. | Max. | Min. | | |
| | | | | | | inches. | inches. | ° | ° | inches. | days. |
| 1862 | 44 | 11 | 17 | 17 | 11 | 30·70 | 29·20 | 90 | 10 | 10·03 | 104 |
| 1863 | 30 | 16 | 24 | 20 | 10 | 30·85 | 29·20 | 90 | 16 | 14·99 | 38 |
| 1864 | 31 | 20 | 22 | 18 | 9 | 30·59 | 29·40 | 95 | 4 | 19·07 | 62 |
| 1865 | 39 | 12 | 21 | 16 | 12 | 30·65 | 29·20 | 94 | 11 | 21·10 | 55 |
| 1866 | 30 | 16 | 18 | 18 | 18 | 30·40 | 29·17 | 90 | 14 | 34·28 | 5 |
| 1867 | 19 | 14 | 16 | 12 | 39 | 30·60 | 28·60 | 95 | 14 | 10·48 | 12 |
| 1868 | 27 | 15 | 10 | 9 | 38 | 30·33 | 29·34 | 91 | 11 | 23·04 | 64 |
| 1869 | 28 | 17 | 25 | 13 | 17 | 30·90 | 29·38 | 100 | 15 | 13·64 | 35 |
| 1870 | 37 | 10 | 17 | 10 | 26 | 30·12 | 29.13 | 89 | 11 | 20·68 | 37 |
| 1871 | 37 | 17 | 13 | 8 | 25 | 30·76 | 29·55 | 92 | 1 | 20·34 | 57 |
| Average for 10 years | 32 | 15 | 18 | 14 | 21 | .. | .. | .. | .. | 18·76 | 47 |

Notes.

Wind:—

Its relative force may be stated thus

| N.W. to N.E. | N.E. to S.E. | S.E. to S.W. | S.W. to N.W. |
|---|---|---|---|
| 4 | 3 | 2 | 1 |

In April, 1869, a gale from the N. attained a force of 19 lbs. per square foot, and in February, 1870, of 21 lbs. per square foot, during a gale from N.N.W.

Rain:—

On the 31st August, 1868, 7¼ inches of rain fell in 24 hours.

The 'fetch' of the sea from various directions at Sulina may thus be stated:—

| Direction | N.E. | E. | E.S.E. | S.E. | S. |
|---|---|---|---|---|---|
| Fetch in nautical miles | 116 | 150 | 537 | 257 | 230 |

Although the 'fetch' from E.S.E. is much the greatest, the waves generated in that direction, although they attain a greater height, are much less dangerous than waves which are raised by N.N.E. and N.E. gales. This is owing not only to the greater force and longer duration of the latter, but to the comparatively shallow water over which they travel.

V.—Synopsis of Observations and Calculations concerning the discharge of the entire volume of the Danube, from 1862 to 1871 inclusive.

| Year. | Height of Surface of River above the Sea at Toultcha, 50 miles from Sulina. | | | Surface Velocity per Minute at Sulina. | | Volume of Water discharged, and Weight of Detritus carried in Suspension to the Black Sea. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Volume of Water discharged per Second. | Weight of Detritus held in Suspension per Cubic Foot of Water. | | | Proportion of Weight of Detritus to Weight of Water. | | | Weight of Detritus discharged per annum. |
| | Mean. | Maximum. | Minimum. | Maximum. | Minimum. | Mean. | Mean. | Max. | Min. | Mean. | Maximum. | Minimum. | Mean. |
| | ft. in. | ft. in. | ft. in. | ft. | ft. | cubic feet. | grains. | grains. | grains. | | | | tons. |
| 1862 | 4 6 | 10 0 | 1 6 | 500 | 25 | 166,000 | 100 | 767 | 12 | 1/4375 | 1/570 | 1/36460 | 33,300,000 |
| 1863 | 3 0 | 6 6 | 1 0 | 144 | 40 | 125,000 | 70 | 266 | 10 | 1/6250 | 1/1645 | 1/43750 | 17,600,000 |
| 1864 | 6 0 | 8 9 | 1 0 | 310 | 10 | 200,000 | 230 | 940 | 13 | 1/1902 | 1/463 | 1/33650 | 92,500,000 |
| 1865 | 6 0 | 10 6 | 1 0 | 480 | 25 | 200,000 | 150 | 706 | 6 | 1/2917 | 1/620 | 1/73000 | 60,300,000 |
| 1866 | 3 0 | 5 6 | 1 3 | 125 | 40 | 125,000 | 50 | 162 | 20 | 1/8750 | 1/2700 | 1/21870 | 12,500,000 |
| 1867 | 6 0 | 9 0 | 1 6 | 290 | 40 | 200,000 | 130 | 280 | 25 | 1/3365 | 1/1560 | 1/17500 | 52,300,000 |
| 1868 | 6 0 | 10 0 | 1 0 | 160 | 31 | 200,000 | 130 | 345 | 38 | 1/3363 | 1/1268 | 1/11500 | 52,300,000 |
| 1869 | 4 0 | 7 6 | 1 3 | 220 | 51 | 145,000 | 180 | 610 | 52 | 1/2430 | 1/717 | 1/8410 | 52,500,000 |
| 1870 | 8 6 | 11 3 | 4 3 | 376 | 86 | 325,000 | 230 | 585 | 92 | 1/1902 | 1/748 | 1/4735 | 150,300,000 |
| 1871 | 9 6 | 14 3 | 2 3 | 450 | 90 | 383,000 | 200 | 770 | 53 | 1/2187 | 1/568 | 1/8235 | 154,000,000 |
| Average for 10 years | .. | .. | .. | .. | .. | 207,000 | 147 | .. | .. | 1/3060 | .. | .. | 67,760,000 |

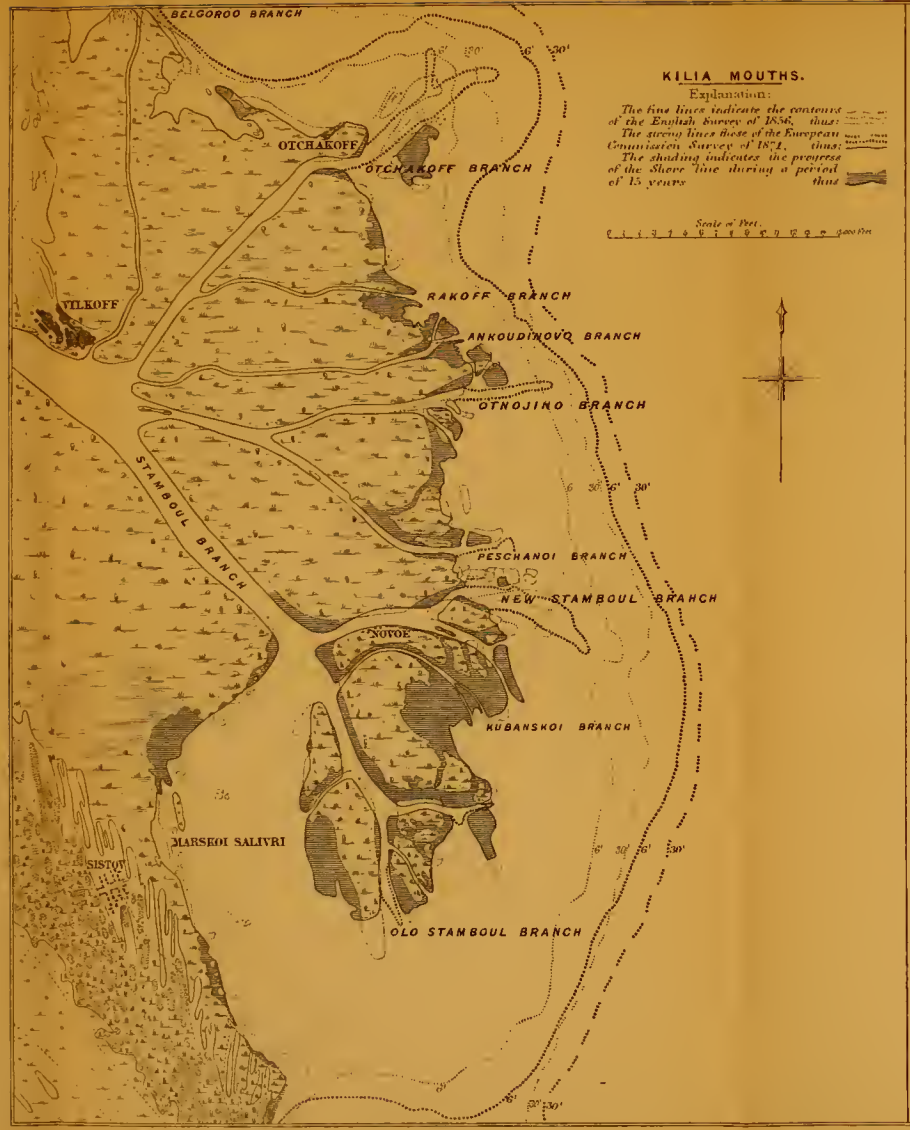
Notes.—The relative proportions of water and detritus discharged by the Danube at different periods may be stated approximately as follows:—

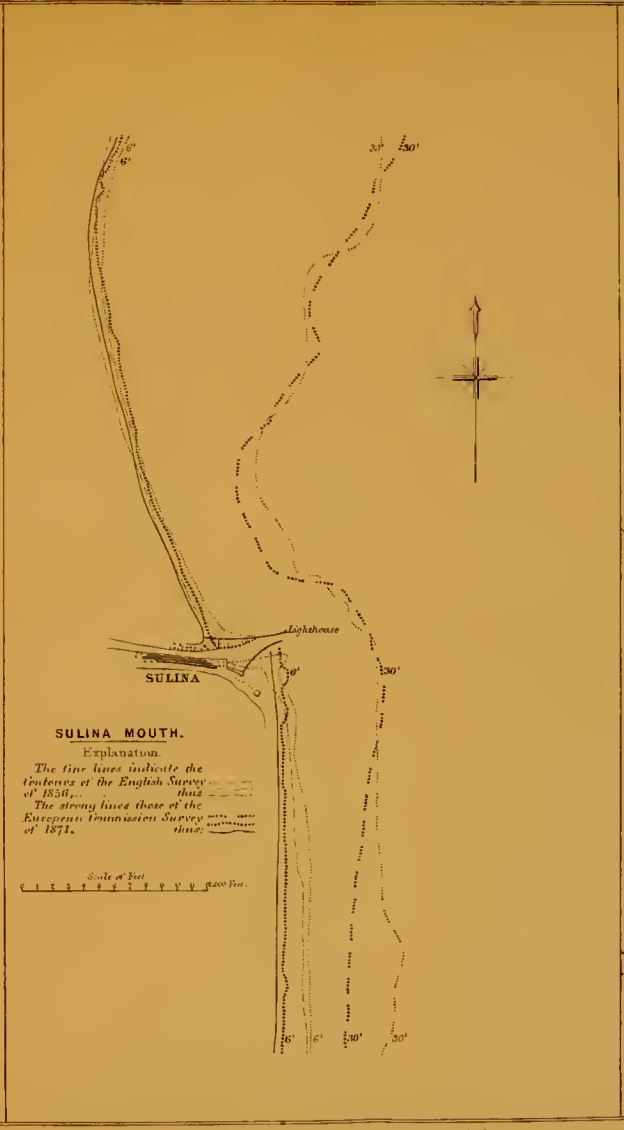
| —— | Volume of Water in Cubic Feet per second. | Weight of Suspended Matter in Tons per day of 24 hours. |
|---|---|---|
| Extreme low water . . . . | 70,000 | 11,000 |
| Ordinary low water . . . . | 125,000 | 30,000 |
| Ordinary high water. . . . | 324,000 | 410,000 |
| Extraordinary flood . . . . | 1,000,000 | 2,500,000 |
| Mean for ten years . . . . | 207,000 | 180,000 |

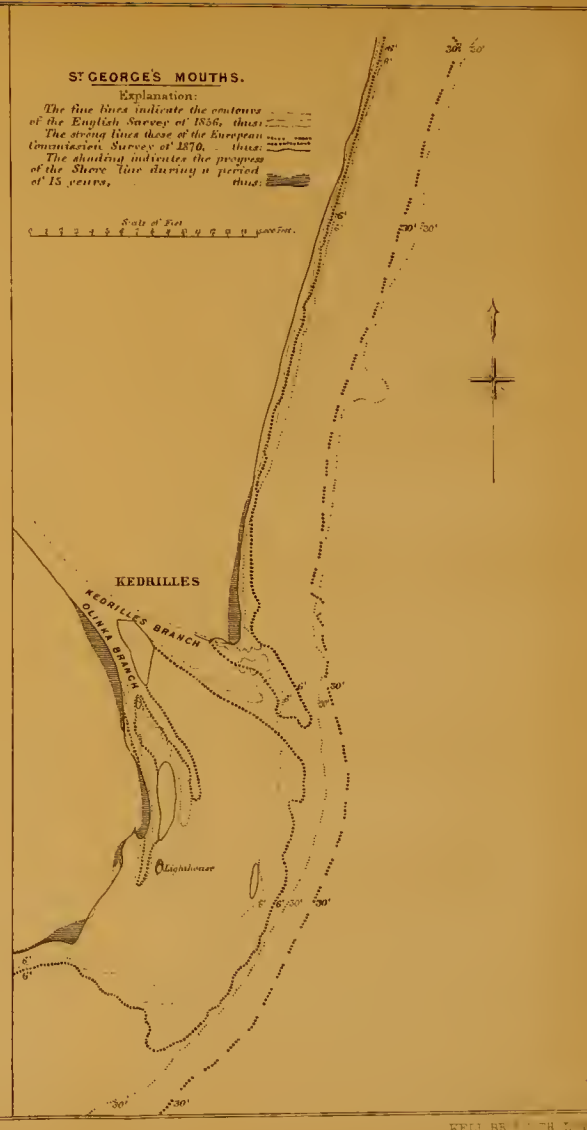
The weight of the detritus held in suspension is the result of experiments made regularly, ten times a month for ten years, on the effluent surface waters in mid channel in the Port of Sulina.

According to the researches of M. Surelle, a French engineer, the quantity of earthy matter suspended in the Rhone in its course through the delta increases from the surface to the bottom, the proportion between the two being as 100 is to 188.

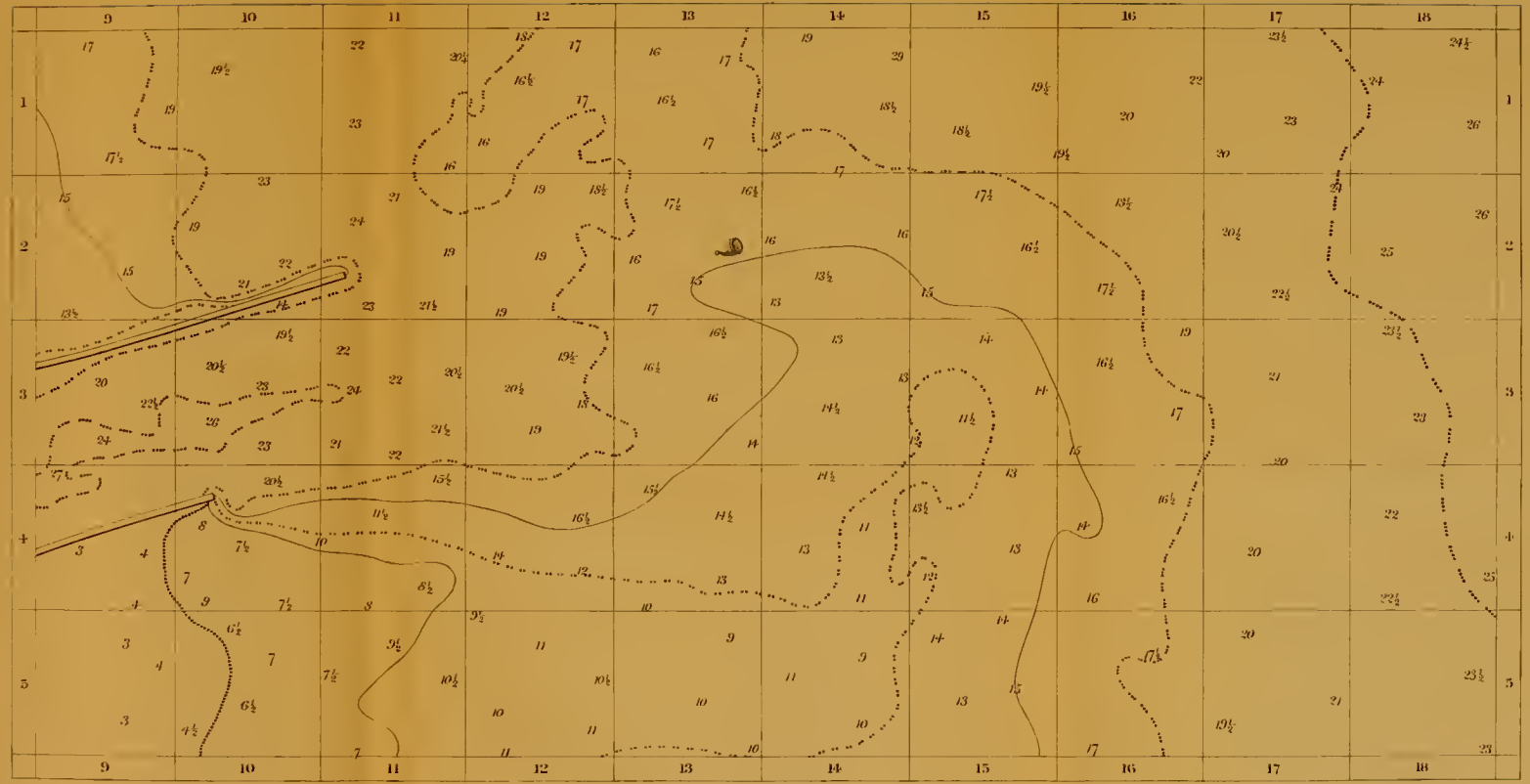
# THE DELTA OF THE DANUBE.





Lighthouse
SULINA
SULINA MOUTH.
Explanation.
The fine lines indicate the contours of the English Survey of 1856, thus
The strong lines those of the European Commission Survey of 1871. thus:
Scale of Feet

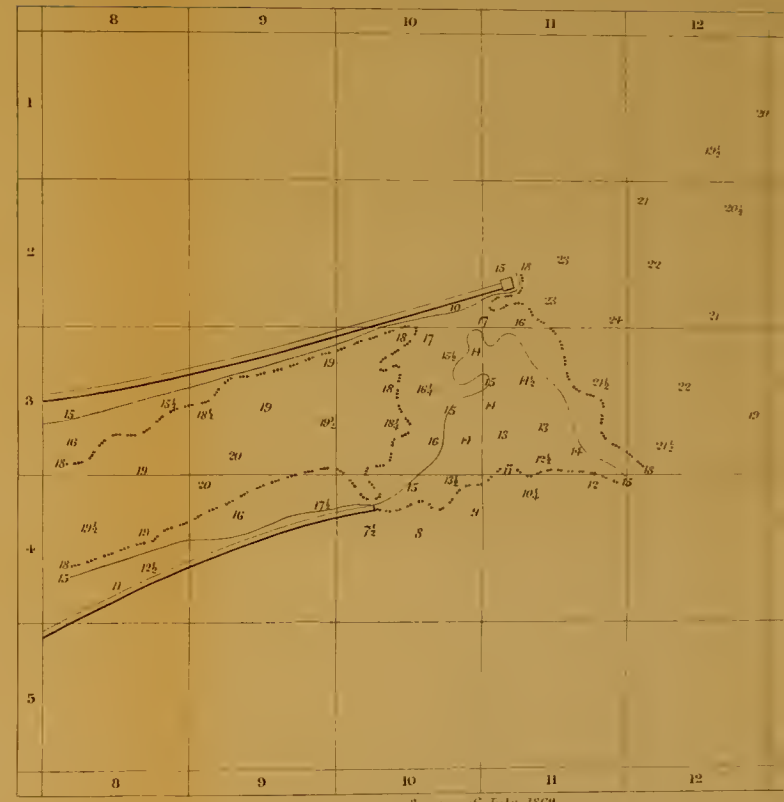

St GEORGE'S MOUTHS.
Explanation:
The fine lines indicate the contours of the English Survey of 1856, thus:
The strong lines those of the European Commission Survey of 1870, thus:
The shading indicates the progress of the Shore line during a period of 15 years, thus:
Scale of Feet
KEDRILLES
KEDRILLES BRANCH
SULINA BRANCH
Lighthouse

The side of each square is equal to 500 Feet.



*Survey of May, 1865*

SHOWING THE STATE OF MOUTH OURING SPRING FLOODS.

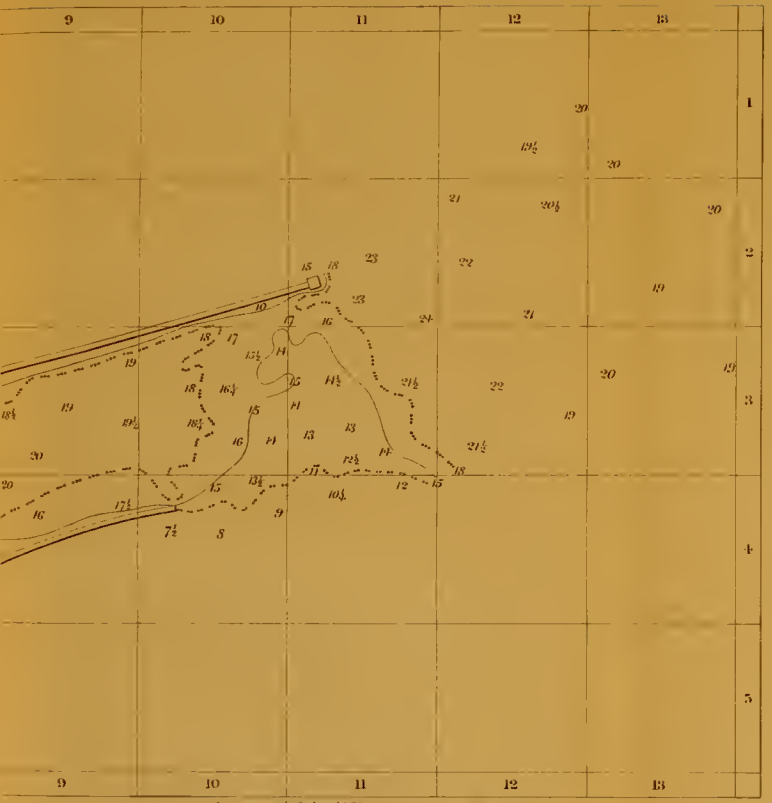


*Survey of July, 1869*

STATE OF MOUTH AFTER A LONG SEASON OF LOW WATER.

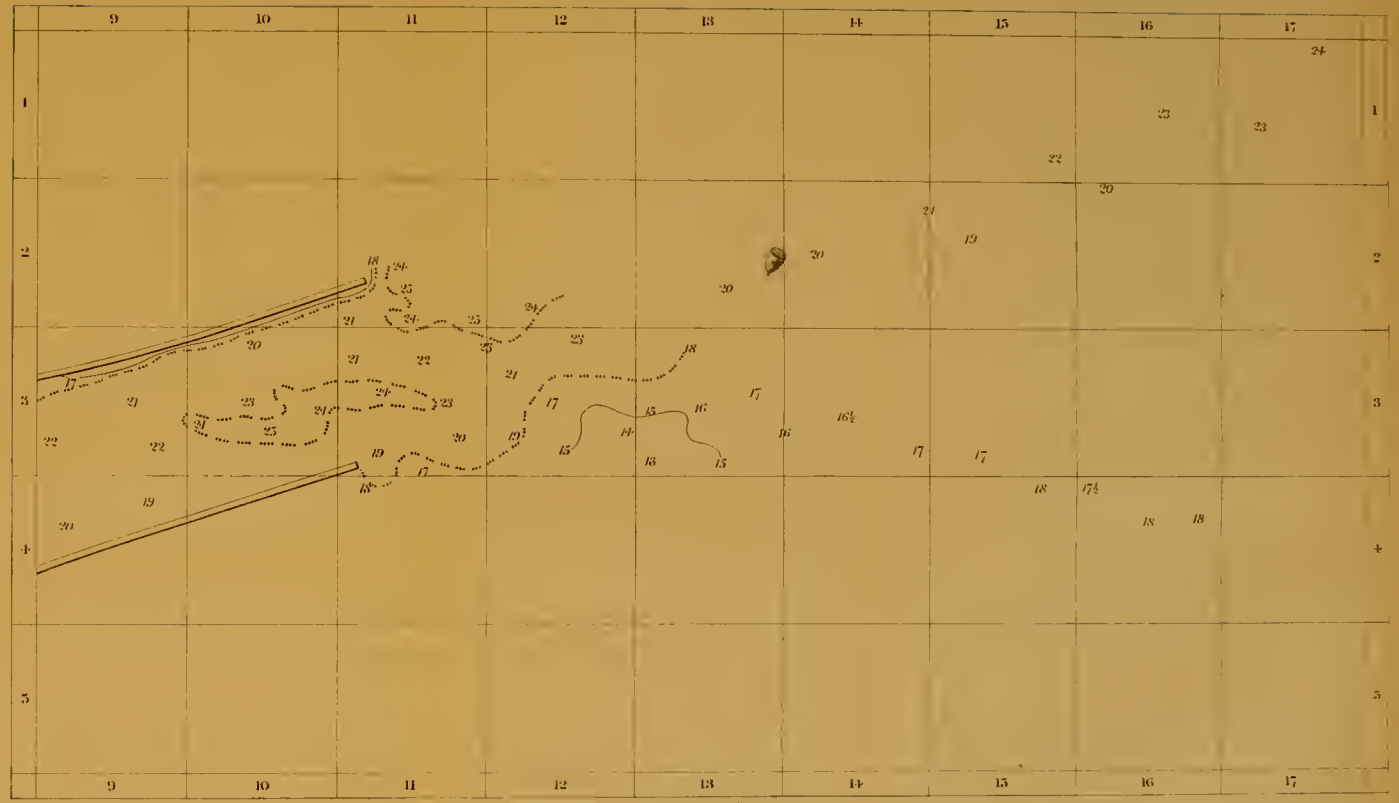
A HARILEY DEL.

The side of each square is equal to 500 Feet.



*Survey of July, 1869*

STATE OF MOUTH AFTER A LONG SEASON OF LOW WATER.



*Survey of April 1870.*

STATE OF MOUTH THREE YEARS AFTER THE EXTENSION OF THE SOUTH PIER.

SULINA
Shore line of 1871
Shore line of 1856
Extension 1871
No 1.
No 2.
No 3.
Extension
Pilots & Boatmen's
Shore line of 1871
Shore line of 1856
SULINA MOUTH.
The side of each square is equal to 500 Feet

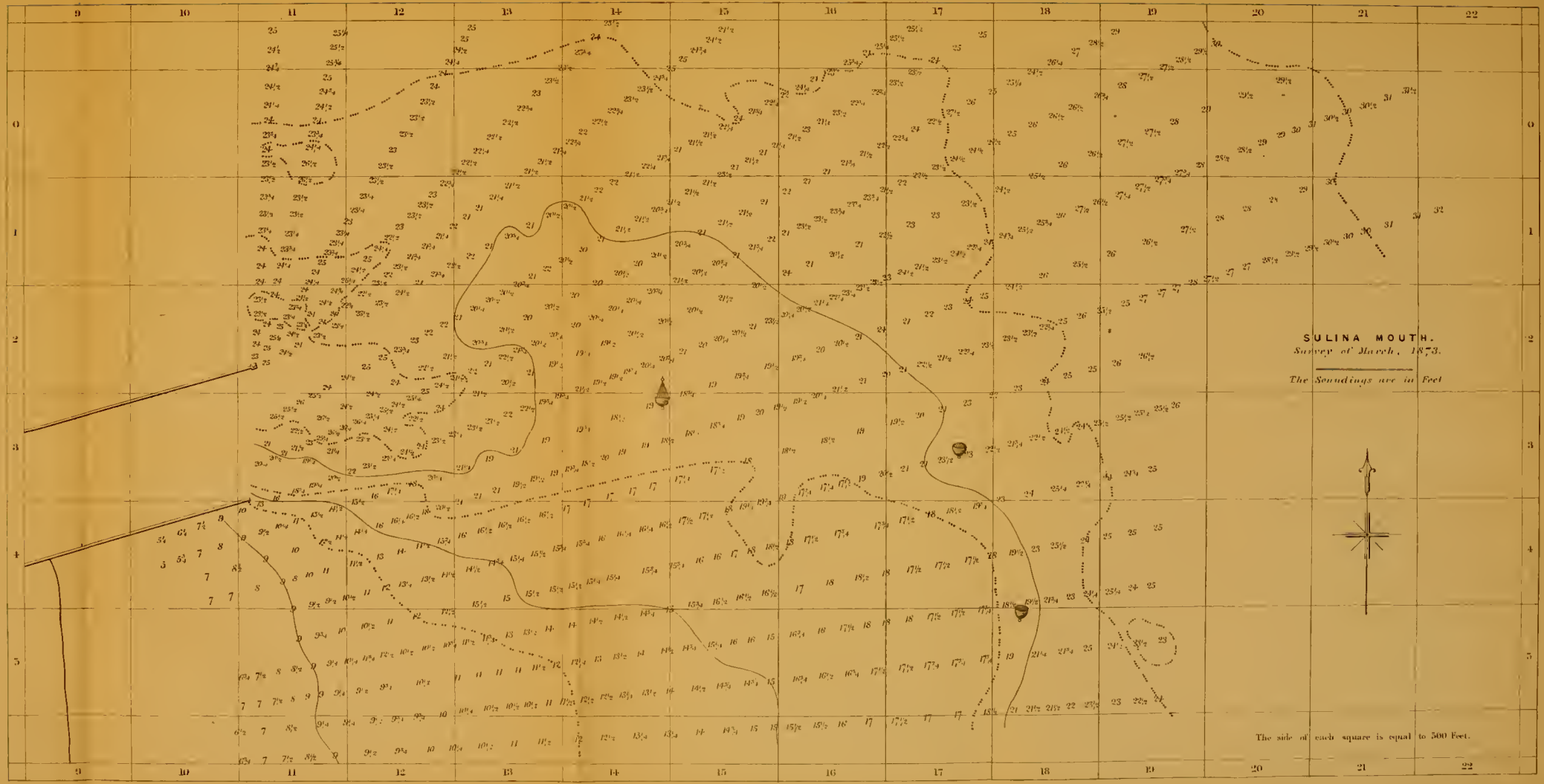
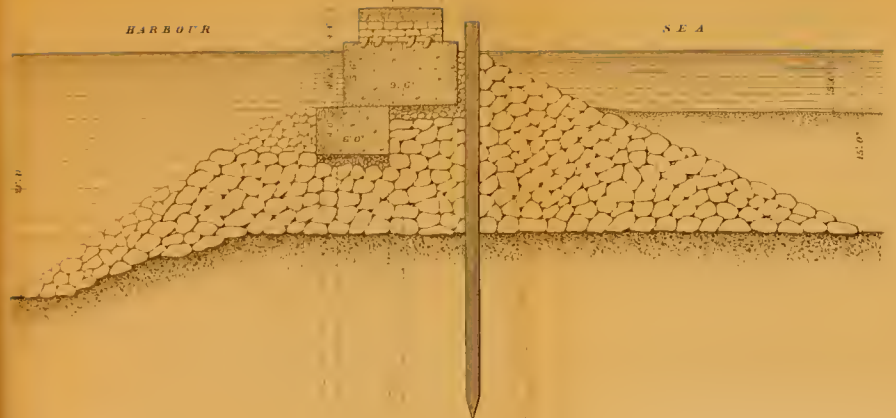
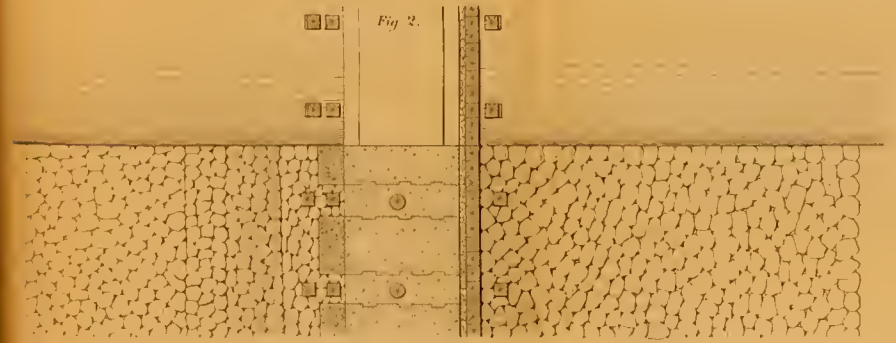

SULINA MOUTH.
Survey of March, 1873.
The Soundings are in Feet
The side of each square is equal to 500 Feet.

Fig 1



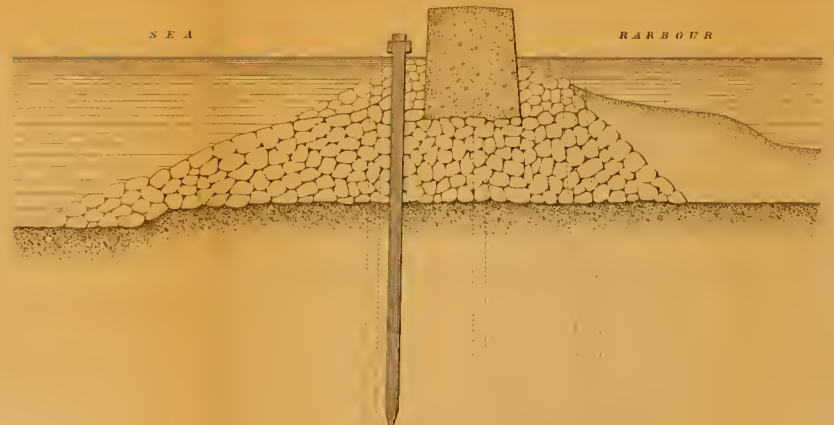

SOUTH PIER. CROSS SECTION NEAR PIER HEAD.

Fig 2.



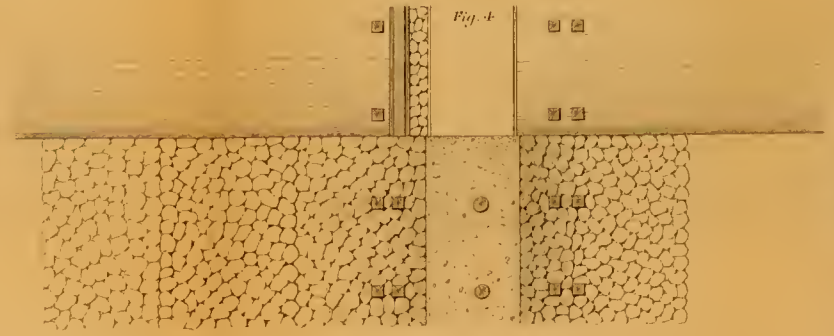
SOUTH PIER PLAN NEAR PIER HEAD.

Fig 3.



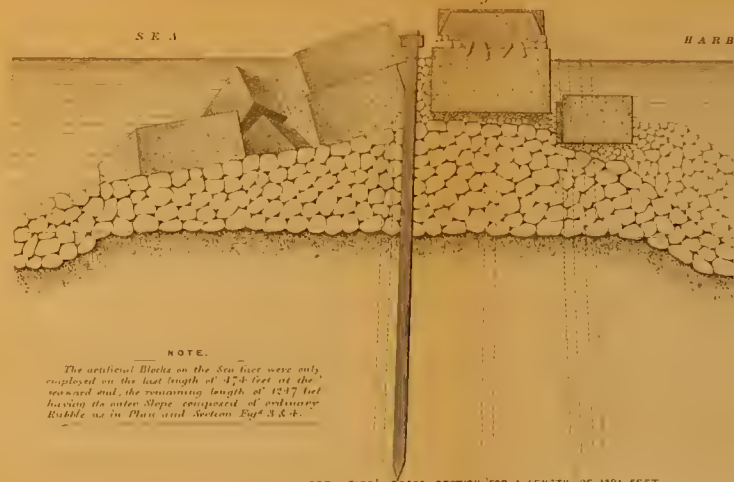

NORTH PIER. CROSS SECTION FOR A LENGTH OF 2791 FEET AT SHORE END.

Fig 4



NORTH PIER. PLAN FOR A LENGTH OF 2791 FEET AT SHORE END.

Fig 5

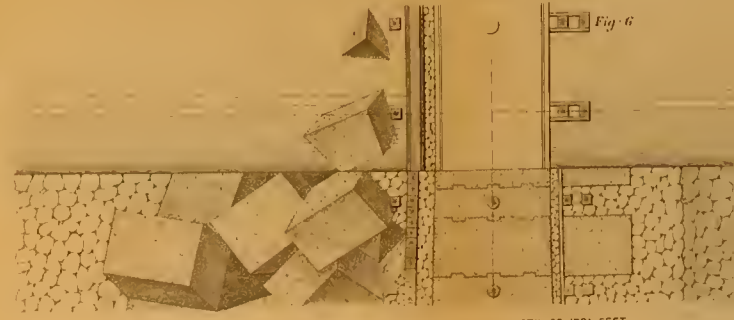



NOTE.

*The artificial Blocks on the Sea face were only employed on the last length of 474 feet at the seaward end, the remaining length of 1247 feet having the outer Slope composed of ordinary Rubble as in Plan and Section Figs 3 & 4.*

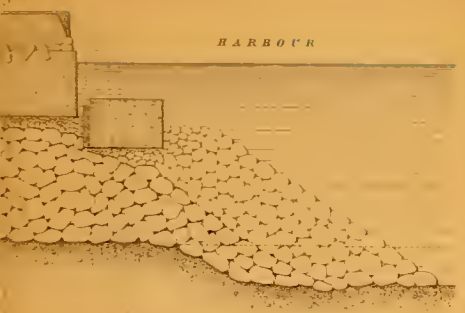
NORTH PIER. CROSS SECTION FOR A LENGTH OF 1721 FEET.

Fig 6



NORTH PIER. PLAN FOR A LENGTH OF 1721 FEET.

Fig 5

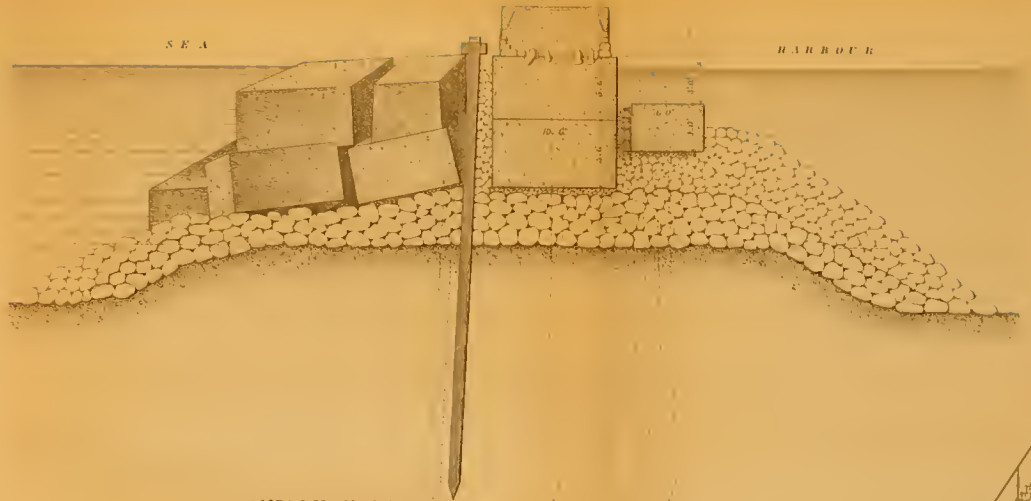



FOR A LENGTH OF 1721 FEET.

Fig 6.

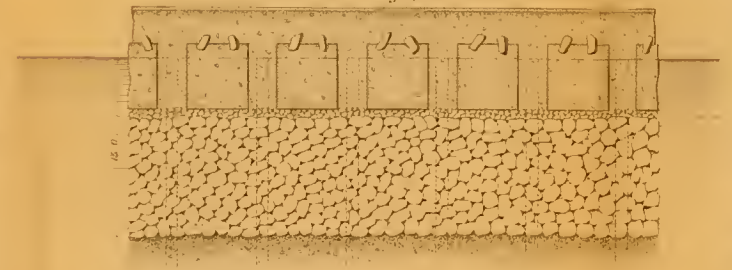
A LENGTH OF 1721 FEET.

Fig 8



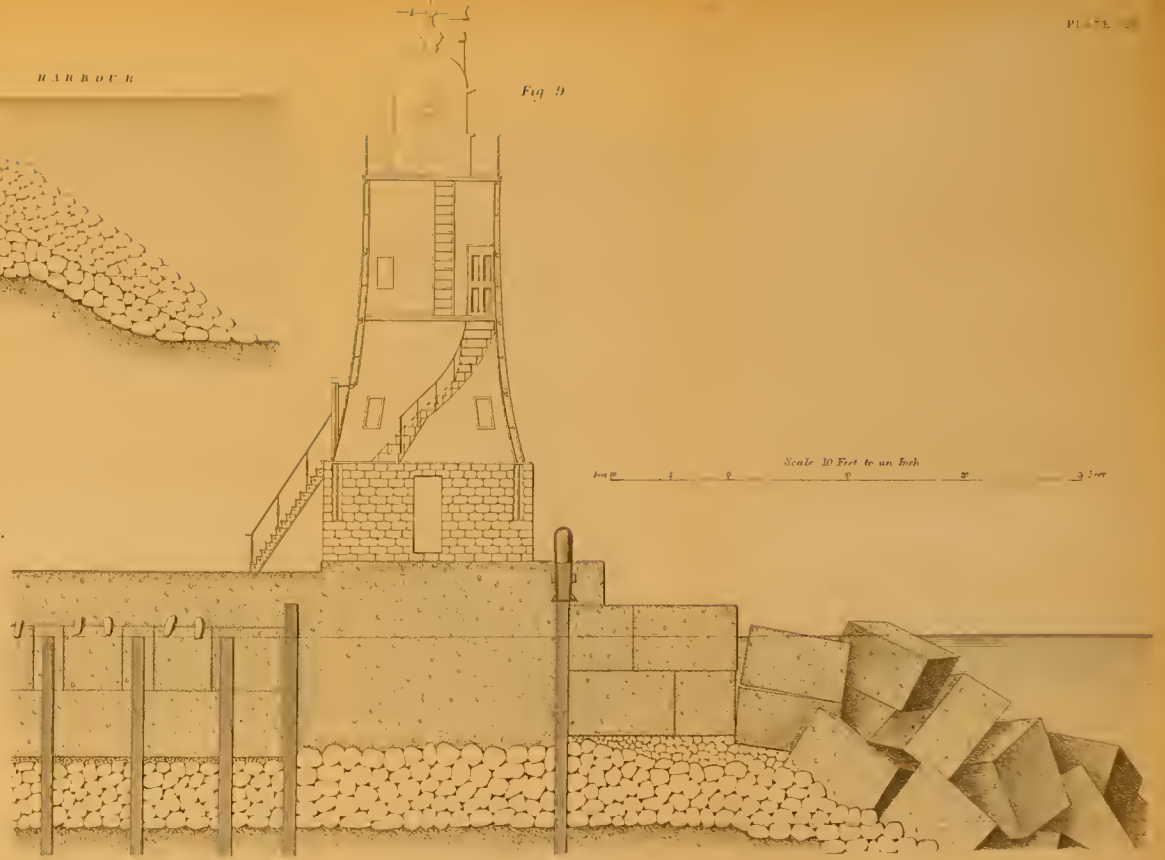

NORTH PIER. CROSS SECTION FOR A LENGTH OF 100 FEET NEAR PIER HEAD.

Fig 7.



NORTH PIER. LONGITUDINAL SECTION FOR A LENGTH OF 1721 FEET.

Fig 9




NORTH PIER. LONGITUDINAL SECTION AT HEAD.

VI.—Analysis of Danube Deposits, by Henry K. Bamber, Esq., F.C.S., London, from specimens sent to him from Galatz and Sulina by the Author.

Specimen No. 1 was taken from the river bank at 2 ft. above low-water level at Galatz. Specific gravity 2·722
" 2 " " " 3 " " " " " " 2·700
" 3 " " " 3 " above high-water level " " " 2·700
" 4 " from the residue of a cubic foot of flood river water at Sulina. " " 2·554
" 5 " " " low river water " " " 2·482
" 6 " from the sea shore at the level of the sea " " " 2·780

In all cases the moisture was driven off before the Analysis was made.

Composition in 100 parts of the Dried Substances.

| | Specimen No. 1. | | Specimen No. 2. | | Specimen No. 3. | | Specimen No. 4. | | Specimen No. 5. | | Specimen No. 6. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soluble in dilute acid:— | | | | | | | | | | | | |
| Silica | 0·400 | | 0·397 | | 0·450 | | 1·193 | | 0·540 | | 0·134 | |
| Oxide of iron | 4·838 | | 6·079 | | 8·229 | | 10·160 | | 10·514 | | 2·982 | |
| Lime | 4·382 | | 5·517 | | 6·335 | | 5·190 | | 5·662 | | 7·441 | |
| Magnesia | 1·110 | | 1·779 | | 1·456 | | 2·281 | | 3·407 | | 1·963 | |
| Carbonic acid | 3·175 | | 3·438 | | 3·716 | | 3·854 | | 4·018 | | 6·445 | |
| | | 13·905 | | 17·210 | | 20·186 | | 22·678 | | 24·141 | | 18·965 |
| Insoluble in dilute acid:— | | | | | | | | | | | | |
| Silica | 72·210 | | 65·698 | | 62·526 | | 53·543 | | 48·345 | | 71·100 | |
| Alumina | 10·358 | | 10·738 | | 11·452 | | 16·010 | | 12·620 | | 6·810 | |
| Lime | 1·447 | | 1·658 | | 1·120 | | 1·175 | | 1·395 | | 1·442 | |
| Magnesia | 0·559 | | 0·567 | | 0·362 | | 1·144 | | 1·073 | | 0·408 | |
| | | 84·574 | | 78·661 | | 75·460 | | 71·872 | | 63·433 | | 79·760 |
| Organic matter | | 1·490 | | 2·853 | | 2·863 | | 5·404 | | 12·180 | | 1·350 |
| | | 99·969 | | 98·724 | | 98·509 | | 99·954 | | 99·754 | | 100·075 |

Mr. W. A. Brooks said, no one could doubt that a great improvement had taken place at the Sulina mouth. When the question of the Danube works was formerly before the Institution, he had made certain recommendations based on the case of the harbour of Swinemunde, in the Baltic,[1] and he was glad to see that, to a certain extent, they had been carried into effect, and that, from the line on which the piers were being constructed, there was a probability of their being kept in the direction which had been given to those at the harbour of Swinemunde, in the Baltic. If the additional works were carried out as he then recommended, the result would be that the current of the ebb would have greater effect in carrying away the deposit which was now taking place in advance of the entrance to the port. The works appeared to have been carried out economically.

As regarded the question of the best system of improving rivers, he was not prepared to assert, as a general law, that it was desirable, in all cases, to commence at the mouth. An Engineer should try and improve the condition of the worst portion of the river. When there was a shoal in the middle of a river, that should be operated upon first; it would not do to treat the head or the tail of the river in order to remove such an impediment. In the Tyne, the Tees, and the Clyde, the governing shoals had been first dealt with. It was useless to commence works in a portion where there was no occasion for improvement. He considered that the Author had exercised a wise discretion in not giving greater slopes than $1\frac{1}{2}$ to 1 and 2 to 1 on the seaward sides of the Sulina piers. It was reasonable to conclude that the great deposit which would immediately take place on the extension of the piers would prove a better natural protection than could be procured by any greater deposit of stone; and that was shown by the shoal water which was now found at the back or seaward sides of the north pier and of the south pier. There was no lift of tide there to bring in a heavier sea. In the case of the Tyne south pier there had been a great amount of material wasted by giving an unnecessarily great slope to its seaward side, and the costly masonry of which it was composed was buried in the mass of sand which had accumulated there.

Mr. J. Abernethy said, it might be taken as a general rule that there was considerable risk in projecting piers from the mouths of rivers to a great distance seaward, as had been done in the case of the Sulina mouth. If there was not sufficient littoral current

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxi., p. 297.

round the coast to remove the deposit brought down by the rivers, the result would be the formation of bars by the accumulations at their mouths. In the case of the Danube—where there was a long range of coast, and the greatest force of the current was in a given direction—when the piers were first projected, it was apprehended that the effect would be an accumulation of sand upon the landward end of the pier, and that the projection of the piers would merely extend the bar further out to sea. There were one or two examples of that within his own knowledge. A similar result to that of the Sulina had taken place in the case of the harbour at Aberdeen. To the north of that harbour there was a long extent of sandy beach for 20 miles, and in north-easterly gales it was expected that the action of the waves would drive the sand into the mouth of the river Dee. There was a bar across the mouth of the river in ancient times, which was almost dry at low water. To remove that bar Smeaton first, and subsequently Telford, projected a north pier, which, under Mr. J. Hawkshaw, Past-President Inst. C.E., and himself, was being further extended. It was at first apprehended that the result of its construction would be an accumulation of sand on its north side, and that, eventually, the bar would simply remain further out to sea; but the effect had been that the entrance was now brought within the action of the littoral current. Such had also been the case at the Sulina mouth; there, although a long pier was constructed on the north side, it was evident that the littoral current acted so strongly that all deposit was carried to the southward of the entrance. After heavy floods there would probably be a slight bank formed beyond the pier heads, but he had no doubt the action of the sea as described would disturb and remove it. On the whole, he thought the improvement of the Sulina mouth was a successful work, and that the projectors were warranted in substituting permanent works for those which had been, formerly, temporarily and experimentally executed.

Mr. G. H. Phipps said, the treatment of such rivers as tended to shoal up by the gradual formation and growth of deltas at their mouths, as practised by Smeaton, and generally by the eminent Engineers who had followed him, was that of concentrating the waters into narrower and deeper channels, whereby, the hydraulic mean depth being increased, a moderate slope of their longitudinal surface sufficed to produce a velocity competent to scour the bottom efficiently. The effect of the sea walls at the Sulina mouth of the Danube was precisely of that character. They concentrated the effluent water, and enabled it to break through the barrier of the sandy delta. The passages in the Paper which spoke of the alter-

nations in the character of the effluent water, from a condition highly charged with alluvial matter to that of extreme clearness, and, while in the latter state, to the great efficiency of its scouring power, reminded him of the theory broached by Mr. T. Login, M. Inst. C.E., as to the relative transporting and scouring power of water in a clear state, and when highly charged with mud or silt;[1] the practical deduction being, that clear water possessed a power of scouring a river bed so much greater than that of turbid water, as to allow of a much sharper inclination being given to the channel without injury to the banks. Mr. Phipps must be permitted to state his objection to a theory which had been propounded, namely, that the effect of scour should be attributed entirely to the weight of the passing water. Now it was always held, as one of the first principles of hydrodynamics, that scour was entirely attributable to the velocity of the water passing over the surface of any conduit, and that its effect was, as the square of such velocity. It was well known, that with any water-course in train, equal speeds of the current could be obtained either by a quick fall with shallow water, or by deeper water with less fall, and that therefore the scour upon the bottom would, in both cases, be equal, although the weight of water passing along might differ widely.

Mr. Redman said, he could see no analogy between the tidal harbours of our coasts and the outfall of a river like the Danube, which emptied itself into a comparatively tideless and inland sea. The Danube was an example of a river which, prior to the operations carried out by the Author, had, in a very small degree, had its resources developed by the art of the Engineer. It was a striking example in many parts of its course of how Nature apparently revenged herself for the neglect of man. From its source in the court-yard of a German palace, it had a distance to its mouth, in a direct line, of 1,600 miles or 1,700 miles, and, including its windings, its length was about 2,000 miles. Passing through very varied country below Pesth, those acquainted with the river knew the constant alterations of its direction through the alluvial plains, and that as it increased its length it decreased its power. They might, in passing down the river below Pesth, see that operation constantly going on even as the vessel passed down. In the large plantations of willows they saw the action of the river on the concave sides of its windings, and slabs of alluvial falling, while

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxvii., p. 545, and vol. xxviii., p. 84.

the willows and green herbage thereon fell with them into the river. On the convex sides, spits of sand were constantly growing out towards the hollow concave sides. Those changes went on until approaching Galatz and the head of the delta. Below Galatz the river bifurcated into the main northern channel, the Kilia branch, and the southern, the St. George's channel, joining the Black Sea by three channels, the central Sulina branch being a tributary of the southern, or St. George's channel. The courses were so tortuous that three-quarters of the compass were passed through in proceeding down the Sulina in a vessel. The northern channel, the Kilia, threw out a smaller delta beyond the great delta. The great delta was 60 miles by 30 miles, and contained an area of about 900 square miles; the entire delta being estimated at 1,300 square miles. The northern branch threw out a similar delta—which would be accounted for by referring to the approximate volumes of the various branches given by the Author—that again caused the Kilia branch to be divided into five branches like the extended fingers of a hand. The St. George's branch was the branch selected by Captain Spratt, whose surveys were so well known; and in a report made prior to the Crimean war, he stated it to be that which was most likely to be benefited permanently by works at its entrance. The Sulina branch was really an off-shoot from the St. George's branch; but, from various reasons given, it was selected to be first experimented upon. The normal depth of water over the bars was from 7 ft. to 8 ft. There was now immediately seaward a depth of from 20 ft. to 30 ft., and a greater depth in the channels inland. The result of the temporary works had been to give 17 ft. constant depth over the bar, and that, no doubt, was a great result, as shown by the plans published from time to time by the International Commission. Captain Spratt, in his report, suggested the ultimate probability that those piers would have to be extended as the shoals or the materials deposited at the mouth of the river decreased the depth seaward. That result apparently had not yet taken place; but still the extension of the south pier, described by the Author, appeared somewhat to indorse the conclusion arrived at by that officer.

There was another river on the other side of the Atlantic—the Mississippi. It had a course of about 4,000 miles, or about double the length of that of the Danube. It joined the ocean by three similar mouths, upon which were situated the great trading city of New Orleans. The state of the outfalls of that river was described in a daily journal as being in such a condition that the northern and southern channels had silted up, and the centre channel was now

in such a precarious condition as to excite a fear that, owing to the great amount of material constantly deposited and shifting in the outfall of the channel, very extensive works would be required to maintain the commerce that had hitherto frequented that city.

The importance of the subject of the Danube outfalls had long engaged attention. In a report on the commerce of the ports of New Russia, Moldavia, and Wallachia, made to the Russian Government in 1835, by order of Count Woronzow, by Julius de Hagemeister—the original of which had been published at Odessa, and subsequently translated by T. F. Triebner, and published in London in 1836—the early condition of the Port of Sulina—or 'Soulinah'—was described as follows:—

"The principal ports of the Black Sea are situated at the mouths of the three great rivers; Galatz, Brailoff, Reni, and Ismail on that of the Danube. Betwixt Brailoff and Soulinah the river is in no place less than 18 feet in depth. Of the three mouths of this river, that of Soulinah is alone navigable, and, according as the wind may be, it is from 11 feet to 13 feet deep. From the extreme lowness of the shore from Cape Caliacri, the entrance into the Danube is a very difficult one, its mouth being covered with reeds, and the wind very often blows in the sand to that degree, that even vessels of but small burden are compelled to discharge part of their cargo before they can enter. Without this precaution, vessels of 1,000 or 1,200 chetwerts can rarely pass Soulinah; and it sometimes happens that they are caught by a gust of wind in passing out, and cannot re-enter the river; so that they are obliged to make for sea, and thus see themselves separated from the boats which bring part of their intended cargo, and which are not unfrequently lost, from the impossibility of their living in anything like a heavy sea. This will account for the lighters stationed at the river's mouth (which in 1834 were twelve in number, but now are reduced to three) receiving sometimes as much as 1,000 Turkish piastres for the conveyance of a single cargo."[1]

Mr. W. Parkes said, when the project for the execution of the works described in the Paper was first started, many persons, of whom he confessed he was one, were not very sanguine as to its success. He was glad to find that his fears had not been realised, inasmuch as the success seemed, if not complete, to have been very considerable. But he thought there was scarcely a large river in the world the mouth of which was navigable except by the aid of

[1] "Report on the Commerce of the Ports of the Black Sea." 1 vol. 8vo. London: Effingham Wilson, 1836, pp. 18, 84, 85.

the rise of tide; and even where such an advantage existed the navigation was generally bad. He believed the Danube was almost the only case in which the mouth had been rendered navigable by artificial means; and, seeing that it was an exception to so general a rule, it was desirable to ascertain what were the conditions under which it had been made exceptional. There were two natural actions going on. Opposite to each of the mouths of the river there was an accumulation; between the mouths there was an erosion of the shore. If the river had not been there, it was natural to suppose that the whole of the shore would have been eaten away uniformly; and therefore the amount of solid matter brought down by the river was not to be measured by the apparent width of the extension opposite to the mouths, but by the width of that extension added to the width of the recession in the parts between the mouths. This tendency to erosion, from causes independent of the river, was another circumstance conducive to success. In his reply upon the discussion of the previous Paper the Author had said, "that he did not consider it an advantage to have a large body of water discharging at the entrance. That was the only disadvantage of the St. George, as compared with the Sulina. The more the quantity of water, the greater would be the amount of deposit."[1] Mr. Parkes concurred in those remarks, as he considered that the amount of accumulation would be approximately in proportion to the quantity of water which came down each mouth, so that which had less inland water pouring out of it was more susceptible of improvement than the one which brought down a greater quantity. The Sulina mouth was the one which brought down by far the least quantity of water and of solid matter in suspension, and was, therefore, the one least liable to deterioration from deposit; hence it was wisely chosen for improvement. Probably an attempt to improve either of the other mouths would have been less successful.

It would be interesting to discover the action producing that degradation along the coast. In his first Paper the Author stated that:—"The deposits which form the bars, although stretching across the mouths in every case, extend only a short distance to the north, but to a very considerable distance towards the south. This effect is produced by the combined influence of the prevailing northerly winds and of the littoral current, which latter, during these winds, and in calm weather, constantly flows towards the Bosphorus."[2] If this littoral current

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxi., p. 307.

[2] *Vide* Ibid., p. 282.

was solely dependent upon the wind, probably it did not extend much below the surface, and therefore it would be interesting to know whether observations had been made as to the depth to which the water was in motion. It happened that Mr. Parkes was much interested in littoral currents. There were, no doubt, many real ones in different parts of the world; but, in all probability, there were still more which were ideal. A distinguishing characteristic was that a real current generally caused deepening, and an ideal current generally caused silting. Under certain circumstances, the ideal littoral currents were possibly more important in their action than the real ones. He knew of one case in which important works of improvement were retarded for four years entirely by the action of an ideal littoral current. The case before the Meeting was one in which a real current had effected some improvements. It seemed to be well established that there was a surface current, and he should be glad to know whether there was a deep-water current as well.

So much for the natural action going on. He would now turn to the effects produced by the works. The remarkable result presented was an accumulation on the south side, and an erosion of the shore on the north side. The Author suggested that the shore had been eaten away by the action of the waves on the north side, and that the solid matter from the river mouth had been checked as it arrived at the ends of the piers, and driven to the southward. There was, however, one point which appeared inconsistent with that suggestion—the deep-water channel, after leaving the mouth of the river, turned to the northward, from which it might be inferred that the current was diverted in that direction. This did not seem to be consistent with the existence of a littoral current from the northward.

In the Author's first Paper it was stated:—"The north-east winds are the strongest, and blowing over comparatively shallow water, they produce the most dangerous seas. The largest waves are, however, those raised by the south-east gales, which cross a reach of 500 miles."[1] Mr. Parkes was disposed to think that it was the waves raised by the south-easterly winds which were the most important agency. They would seem to have driven the sand along the shore until it was stopped by the piers, while waves from the same quarter, lashing round the ends of the piers, ate away the land which was to the north. That was the result which was

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxi., p. 283.

observable on the coast of the United Kingdom, and in most other analogous cases.

From the description of the walls which had been constructed, he was very glad to find—because it rather confirmed a preconceived notion of his own—that the Author had abandoned the plan of throwing in fresh concrete to make the piers, or rather to complete them, and adopted that of depositing large concrete blocks. Mr. Parkes thought the latter system was gaining ground in engineering practice, and that the former had rather fallen into disuse. No doubt the deposit of fresh concrete was useful under certain circumstances; but for systematic work, he believed it would be found that in the great majority of cases the plan of setting large blocks was very much superior. It could be carried out with much less interruption, and generally at much greater speed, and at less cost. With respect to the proportion of cement to other materials for making concrete, it appeared that, below water, 1 of cement to 3 of sand and gravel was used, and that, above water, the proportion used, namely, 1 of cement to 6 of sand and gravel, did not seem to have been satisfactory; whereas in the blocks which were allowed to harden before being placed, the proportion was 1 of cement to 7 of sand and gravel, and those blocks were ready for use 10 days after they were made. He was glad to find they were used in so fresh a state. In some works in the United Kingdom they were kept for two or three years. That he conceived was a great mistake. The blocks did not harden so completely in air as in water; and there was a considerable loss in the shape of interest on their money value by keeping them so long. At Kurrachee blocks of 27 tons were used, and the proportion of cement was one-tenth of the cubical contents of the block. One of those blocks was set without difficulty 10 days after it was made, and, as a rule, they were placed in the work when 30 days old. He therefore saw no reason, if one-tenth of cement was sufficient, why one-seventh of cement should be used.

He would call attention to a very common confusion which was made in stating the proportion of cement and other materials. He had lately read a very good account of some works abroad in one of the professional journals, and the proportions were given thus:—"5 of gravel, 2 of sand, and 1 of cement, making altogether 7 of gravel and sand to 1 of cement;" whereas it was 5 of gravel and sand, because the sand simply filled in the interstices of the gravel, and added nothing to the bulk. The proper way of stating the proportions of materials was to say the cement was such a proportion of the total cubical contents of the block; the other materials should be

regulated with great care, so that all the interstices should be filled up to make a solid mass. There was another point which required some care in stating the quantities of cement and other materials. In the case he mentioned at Kurrachee he said one-tenth of the total contents of the block was cement. That was true as cement was measured in Kurrachee; but one-tenth, as measured in Kurrachee, would not be one-tenth as measured in England, because during the voyage cement swelled to the extent of 10 per cent., so that the same actual quantity in England would be only one-eleventh of the block. The effect of the long voyage was a slight total increase of weight from absorption of moisture; but when the cement was taken out of the casks it swelled, and became one-tenth less specific gravity than when it was originally sent out from the makers.

In the Paper an interesting fact was mentioned with regard to a large block of concrete. It appeared to have been set and to have stood for some time without the slightest subsidence. A heavy sea came upon it, and it was stated to have then 'succumbed.' That was attributed to the block being undermined. It might be so; but he would mention that blocks, or solid masonry of any kind, subsiding under the action of the waves was by no means a proof that they had been undermined. If they rested upon rubble stone, and the rubble stone upon sand, the sand itself was acted upon by the waves, and the superstructure, whatever it might be, would sink into the sand. At Kurrachee there were opportunities of seeing this on a very large scale. There were every year some eight months of fine weather, with only occasional, and not very heavy, gales. Then there were three months or four months of the continuous heavy weather and high seas of the south-west monsoon. It was found that in the fine weather there was no subsidence of the wall; but during the monsoon, with the sea playing over the works for several weeks together, very considerable but uniform settlement took place. The wall subsided 2 ft. without any displacement of the blocks themselves. That seemed to be attributable to the hydrostatic pressure of the waves alternately on either side of the breakwater producing a kind of 'sawing' action on the sand under the foundation of the works, and rendering it 'quick,' so that the rubble stone could sink into it. That the varying hydrostatic pressure was the cause of the action was, he thought, proved by the fact that the subsidence did not take place to the same extent near the end of the wall, where the waves had free scope laterally round the end of the pier. The work of the first year settled only about 4 in. at the end, and

about 8 in. at the distance of 100 ft. from the end. The work was extended during the succeeding year, and then the first year's work did not subside farther, except near the end, where it had only subsided to a small extent during the first monsoon; but after the second monsoon it was found to have sunk down to the same extent as the portion farther back had done in the first monsoon. In the length constructed during the succeeding year in like manner it was found that up to within 50 ft. or 60 ft. of the end the subsidence was considerable; but the blocks at the extreme end only subsided about half as much as those farther back.

He would call attention to the peculiarity of the section shown in Fig. 8 (Plate 28). There appeared to be a ridge of some material under the superstructure with slopes on either side, on which the rubble stone lay. Was that ridge natural or artificial? If natural, he supposed the sea had brought it into that form. He was informed that something of that kind invariably took place at the Amsterdam Canal. It appeared where that occurred there was no settlement of the superstructure. There was no action of that character in the breakwater works at Kurrachee, although the natural features there were in many respects very analogous.

Mr. David Stevenson said, some years ago the Author was good enough to send him copies of all the reports that had up to that time been made to the Danube Commission, which, at the Author's request, Mr. Stevenson had presented to the Royal Society of Edinburgh. He had carefully read those reports, and had found they contained much that was exceedingly interesting to marine engineers. Reference had been made in the course of the discussion to some of the bar harbours of the United Kingdom; but he confessed what struck him most in reading those reports was the remarkable illustration they afforded that the physical characteristics of such rivers as the Danube were totally different from the physical characteristics of the rivers of the United Kingdom, and that hence there must be a like difference in the proper mode of treating them, and in the works required for their improvement—in short, there was nothing that could be said to be common to both cases. In illustration of this remark, he might refer to the 'bar' of the Danube, which the Author showed was produced entirely by the deposit brought down by the river, amounting sometimes to 27 cubic inches of solid matter per cubic yard of discharge, and when the river was in flood, to no less than 600,000 cubic yards of solid matter in 24 hours. It was also found that the substance of which the Danube bar was composed was identical with that which was brought down by the

river, and that during floods, the deposit being greatest, the bar was in its worst state. Such being the case, he failed to trace any analogy between the Danube and the rivers on the coast of the United Kingdom, such as the Tay, the Wear, or the Tyne. It was now thirty years since he propounded the theory—and at that time he believed he stood alone in holding it—that the bars of the rivers of the United Kingdom were due entirely to the action of the sea constantly heaping up sand and detritus, and that but for some counteracting influence, the effect of that action would be to form a continuous line of beach across the mouths of navigable rivers and estuaries. The counteracting influence to which he referred was that of the tidal and river scour. He might say that that theory, now thirty years old, had been fully confirmed by his subsequent experience. He had examined the outer banks and bars of most of the tidal rivers of Great Britain, and on no occasion had he succeeded in finding traces of alluvial deposit in any of them. It was further known that those bars were always worst after a prevalence of on-shore wind and heavy sea, and were best when the river was in flood. The deposit brought down by the rivers was, in fact, too light to find a settlement on the bar, but was swept out by the ebb current, and often coloured the sea for many miles along the coast. The waves were the true 'depositors' of the bar, the river was only an 'excavator,' and there would still be all the phenomena of a bar at the mouths of estuaries, although the river water did not bring down a single particle of suspended matter. All of that experience, although applicable to the rivers of Great Britain, was quite at variance with the experience obtained on the Danube. In confirmation of his remarks, he might cite the Abbot Castelli, who wrote in the middle of the eighteenth century, attributing the bars on the shores of the Mediterranean to the "violence of the sea;" but who, in explaining his views, said:—"The bar is due to the contrariety of the stream of the river to the impetus of the sea waves; and in the place where these two impediments meet with equal force the sand, which is driven out to the sea by the river, settles down under water, and forms a bar."

Another feature of dissimilarity which occurred to Mr. Stevenson on reading those reports was that, in dealing with the tidal rivers of Great Britain, it was most important not injuriously to exclude the water which enters during the flood tide, and passes out during the ebb tide. But in such a case as the Danube it was not necessary to consider that important and difficult element in designing works for improving the navigation, for there was no reversal of the

current by the alternation of flood and ebb, but simply a continuous stream or current flowing constantly to the sea, and therefore there was no backwater to be dealt with. There was still another difference of feature to be noticed. If his bar theory, as applicable to tidal rivers, was right, it clearly followed that, if the pier heads were carried into water of sufficient depth to prevent the waves from acting upon the bottom with such force as would throw up sand banks, it would be possible to secure permanently the depth obtained by extending the piers, because there would be no submerged beach thrown up by the sea, and the alluvial matter in suspense would be carried out with the current. But at the Sulina mouth, notwithstanding the erection of the piers, there would still be the same discharge of water heavily loaded with the same amount of alluvial deposit, and the same tendency for a bar to form. He thought, from what he gathered from the reports, the commissioners contemplated that an extension of the piers at some future period would be necessary. Great merit was due to the Author for having, in a foreign country, and under great difficulties, successfully completed so extensive a work at a comparatively small outlay.

Sir John Coode said, he was much struck with one point mentioned at the commencement of the Paper, namely, that the material forming the rough deposit at the base of the work was formed of stones of less than 1 cubic foot in size. Granting that they were twice as large as stated, say 2 cubic feet, they certainly could not be considered large masses. After a lapse of two years, that deposit had not been disturbed to a greater depth than from 3 ft. to 4 ft. below the water line, and the slope at which the material had been left by the action of the sea on the more exposed side was only $2\frac{1}{2}$ to 1. He ventured to say, therefore, that the work could not have been exposed to anything like a heavy storm-wave; if such had been the case, the depth to which the material would have been moved would have been about 13 ft. or 14 ft. below the water level, and the slope would have been 5 to 1 or 6 to 1 instead of $2\frac{1}{2}$ to 1.

In reference to the concrete, it was stated in the Paper:—"The first trials were unfortunate. Although a distance of 177 ft. from the shore end of the north pier was successfully completed in the manner described before the termination of the year 1866, six blocks, out of the eight 35-ton blocks built at the same time on the rock work near to the pier head, succumbed to the first heavy gales which followed their construction, notwithstanding the care with which the protecting dams had been made, and the precautions taken against the wash of the sea, by nailing a 4-ft. width of canvas

to the inside of the vertical planking forming the dam at 2 ft. above the stone work, so that half of the canvas might rest on the foundation, and be kept in its place by large stones."[1] In describing the blocks as having 'succumbed,' he understood the Author to mean that they had disintegrated, not that they had been carried away. Sir John Coode inferred this because it was stated that the proportion of the cement to the gravel and sand was only 1 to 4. It appeared also that:—"the cement was tested by Grant's machine to resist a tensile strain of 350 lbs. per square inch after being immersed 7 days in water."[2] That was a high test, and, if cement of that quality was used, he felt certain, from considerable experience, that, if a block formed of those proportions had succumbed, it could only have arisen from some imperfection in the manipulation of the concrete, or from some defect in the mode by which the concrete was got into the water. He had made large quantities of cement in mass under water, and at a considerable depth, with the proportion of 1 of cement to 5 of gravel. He had executed a large amount of such work for some years past, and had built a substantial sea wall to the height of 40 ft. upon it.

There was another point worthy of notice by Members contemplating works of the class described in the Paper—that was the putting in of rough stones in such a manner as to project above the top surface so as to form a key to the block above, where the blocks were formed 'in situ.' He had done that to some extent, but not in the ready and practical mode adopted by the Author.

Some remarks were made as to the clearness of the water in the Danube. It appeared to him, from what had been said in the Paper, that, so far from being clear, the water of that river was frequently very highly charged with alluvial matter, so much so, that he found that the Author mentioned in his first Paper, that in times of flood the Danube discharged upwards of 600,000 cubic yards of diluvial detritus in twenty-four hours. He was sorry he could not agree in a further remark that the speed of a river current was the great means by which its channel might be improved. If that could be proved, it would go far towards the solution of a very difficult problem.

That the diluvial matter brought down by the river had caused the deposit on the Sulina mouth there could be no doubt, and, from the data furnished by the Author, it might be concluded that the balance of force of the waves was really from south to north, for the channel of the river had been diverted in that direction; and,

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[1] *Vide* ante, p. 203. [2] *Vide* ante, p. 207.

adopting that view, Sir John Coode was inclined to think the greatest improvement might have been effected if the south pier had been carried in advance of the north pier. He should be glad if Colonel Stokes would state what was the reason which had actuated the Author in carrying the north pier in advance of the south pier. The indications upon the drawings seemed to show that the south pier should have been carried in advance of the north pier. No doubt, the works executed had been attended with success, inasmuch as they had given a depth of about 20 ft. of water at the time the Paper now before the Institution was written—as compared with a depth of only 9 ft. in 1857—but the question yet remained, would the depth of 20 ft. be permanent, or would it exist for any lengthened period? He had his fears on that point, as he gathered from the Paper that those works were only completed as recently as 1870. The remarkable and rapid changes which had taken place in the Sulina mouth were matters of very great interest. It was to be apprehended, however, that in that, as in many similar cases, the maintenance of the entrance channel was very little more than a race against time; and if that were so, all the greater credit was due to the Author, and to those who had co-operated with him, in carrying out those works so expeditiously and economically. Sir John Coode was of opinion that the 'knuckle' or 'elbow' in the direction of the channel, seaward of the north of the pier, was an indication of an effort of Nature to close up that opening, and that, after the lapse of a few years, it would not be improbable that, where the 4-fathom lines now nearly met, immediately withinside the piers, the navigable depth would be materially deteriorated, for there was now scarcely an appreciable breadth, with 24 ft. depth of water, in that part of the channel.

Reverting for a moment to his previous remarks as to the possible desirability of extending the south pier in advance of the north pier, the remarkable 'zigzag' form of the contour line was, he thought, an indication which would warrant a reconsideration of the opinion that "the greatest improvement might have been effected if the south pier had been carried in advance of the north pier."

Some remarks had been made by Mr. Parkes with regard to the value of blocks of concrete made on shore and deposited after setting, and the advantages of that process as compared with depositing concrete 'in situ.' As a rule, Sir John Coode concurred in those remarks, but, as in all other matters connected with engineering works, and in the construction of sea works more particularly, each case must be judged according to circumstances.

He had lately put down some foundations for a heavy sea work on a rough, rocky surface, where, if he had not deposited the concrete in mass upon the top of the rock, the expense of preparing the bottom to receive blocks would have been somewhere about twice or three times as great, and the time occupied would have been three times or four times as long, as was required to execute the work by means of concrete deposited 'in situ' upon the bottom in 16 ft. of water at lowest spring tides.

With reference to the proportions of concrete, the rule generally adopted by him was, that the proportions should be measured by boxes of different sizes, which formed the gauges of the proportion of cement, sand, and gravel. With respect to the 'sawing' action of the water on deposited material referred to by Mr. Parkes, Sir John Coode thought there was mixed up in that question a matter of very great interest, and one that required careful attention from those who were engaged in sea works. He did not consider it was a 'sawing,' or 'scouring' action, but a 'pumping,' or rather, he might say, a 'hammering' action. Take the case of a sea wall during the time when a heavy sea prevailed —in many cases, in fact, in all cases—except where the work was put down in mass, or within a cofferdam, the joints below low water must of necessity be open. Now it was known that a block of well made concrete when immersed in water lost about two-fifths of its weight. Take a portion of the wall just adverted to, which out of water would weigh, say 1,000 tons, assuming that a wave rose against the face, its weight when surrounded by water would be reduced to the extent of about two-fifths. Therefore there was at one moment a weight of 600 tons, and perhaps at the next, when the wave had receded, the full weight of 1,000 tons. Consequently, the effect in the case which he had assumed amounted in effect to the weight of a hammer of 400 tons acting upon the bottom; and in the case of a work like that described in the Paper, having a foundation formed of loose materials, and put in place not more than two years or three years, it was easy to understand how subsidence would follow. The reason, he thought, why the subsidence was greater in the inshore part of a sea wall than it was at the head, was that, in a sea wall of considerable length the waves at the outer end, running past the extremity of the work, exercised a considerable influence in dragging down the contiguous wave-crest, whilst at some distance back from the extremity, the waves could only rise against the work, and would, consequently, mount higher; thus the 'hammering' action which he had endeavoured to explain would be greater at some distance

within the extremity of a work than at the outer end, and for this reason a greater amount of displacement often took place within the extremities of a work than at the outer end.

In conclusion, he would remark that the case of the Danube was deserving of the attention of those who were disposed to consider tidal water to be the sole agent to be attended to in river improvements, and that fresh water was of no practical value. He did not wish for a moment to underrate the value of tidal water; it was in nine cases out of ten the chief agent by which the mouths of rivers were kept open; but that view, he thought, was often carried too far. It was obvious that without the fresh water the Danube would not possess an entrance channel, and that by that agency it was alone kept open.

Mr. J. F. Bateman, F.R.S., said, he concurred in the observations of the last speaker with reference to the length of the piers. He remembered the Author speaking of the accumulations that had taken place since the construction of the jetty to the south, and the augmented water surface to the north of the works, and Mr. Bateman could not but attribute those occurrences to the amount of material brought by the south-easterly gales which accumulated behind the south pier. It happened that some years ago he constructed an almost similar work at the mouth of a river in the Mediterranean, but on a smaller scale. Persons in the locality and some naval captains were anxious that he should make the north pier the longest, and curve it to the south. His own observations convinced him that the seaweed which prevailed on the coast was carried from the south to the north, and he therefore determined to make the south jetty longer than the north, and to curve it to the northward in the direction of the current; for he had observed that almost all the mouths of the rivers on that coast, after they came to the open sea, made a turn to the north. He therefore followed nature, and built the jetties to aid, instead of to obstruct, what he believed to be the natural forces in existence. The work had been perfectly successful, and large accumulations of seaweed had taken place behind the south jetty, as sand and other material had in the case of the Danube works.

In fact, the accumulation behind the south pier in the case he referred to might be said to be represented by the drawings of the Sulina entrance (Plates 24, 25, 26, and 27). From those it would be seen that an accumulation had taken place to the south in a very short time, while to the north of the jetty there was scarcely any accumulation. The facts he had alluded to he merely mentioned as an illustration of the soundness of the principle he had adopted.

He had no doubt, however, that the Author had been guided by the information he obtained and by the nature of the ground in determining the particular form of the works he had designed. From the Paper it appeared, however, that after a time the south pier was extended to prevent the overlap of the north pier being so great as it was previously, and that the lengthening of the south pier, and hence the relative shortening of the north pier, were attended with the greatest success.

Much had been said about the manufacture of concrete; and if cement of the quality stated, and if sand—the nature of which had not been described in the Paper—of proper quality had been used, the blocks could scarcely have disintegrated in the way they were said to have done. It was contrary to Mr. Bateman's experience, which had been considerable, in many parts of the world, and with various kinds of material. A rough rule by which the proportions of concrete were determined he adopted, for the guidance of foremen and workmen, about thirty-five years ago. This was to take any vessel—no matter of what dimensions, so that they were correctly known—and to fill it with as much gravel as it could be made to hold, by shaking, or beating it down. If gravel and sand were to be mixed, then, by putting in afterwards as much sand as the vessel would hold in addition, and shaking that down amongst the gravel —the quantity of gravel and of sand being respectively measured as they were put into the vessel. When as much sand as possible had been shaken down, as much water was to be poured in as the vessel would hold. The quantity of water would then represent the lime required, the theory being that each particle of sand or gravel should be imbedded in or surrounded by a matrix of cement, and if the amalgamation of the materials were perfect, then the water, which undoubtedly surrounded every particle, would correctly represent the lime or cement to be used; but, as such perfect amalgamation could not be expected, a somewhat larger quantity of cement than water was employed. By this rule a thoroughly cemented mass of concrete was obtained.

The Paper showed by what simple and inexpensive means a great work had been carried out. It was extremely instructive to all Members who had similar works; but he would add his caution to that of Sir John Coode, namely, that no servile imitation of that or any other work should be adopted by the younger Members of the profession, as every work must be considered with reference to its peculiar circumstances. Rivers of great length, running for the greater portion of their course through flat alluvial districts, generally parted with the heavier particles held in suspension,

before reaching the point of embouchure, and the material finally carried to sea was of a light description. The mode of treatment for such rivers would be different to that required by the short rivers of the United Kingdom, where the material brought down was heavier and coarser, and where the pure sandy particles were not deposited until they reached the sea. The character of the Mersey and of the Dee, which were full of pure sand, was in striking contrast to that of many large rivers where there was hardly a particle of sand, and where the deposit consisted of the finest alluvial material, which, when put in motion, was scarcely heavier than the water itself. Such rivers discoloured the sea at a distance of 150 miles from the mainland. That was the case with the Rio de la Plata and several other large rivers. A material which was light might be washed away by a slight current, while in other cases a strong current was required in order to remove the deposit. The current and velocity which had the effect of clearing the mouth of the Danube might therefore be ineffective in the case of other rivers.

Mr. W. Shelford said, the relative value of tidal water and of fresh water in navigable rivers was a subject upon which discussion was desirable. Referring to some notes which he made four years ago, when preparing a Paper for the Institution, "On the Outfall of the River Humber,"[1] he was surprised to find so many points of resemblance between that river and the Danube. Both had large drainage areas. Their waters were highly charged with matters in suspension, those of the Humber amounting to 320 grains, and those of the Danube to 156 grains per gallon. They discharged through alluvial plains, and both had their outfalls towards the east, across which set strong northerly, and north-easterly winds. The shores to the north of their outfalls were degraded by the action of the sea, and the shores to the south of their outfalls were advancing by accretion. Their outfalls were in each case trained—the Humber by Spurn Point, the Sulina mouth of the Danube by piers. But though the two rivers had those points of resemblance, there were essential differences between them. The Humber was a first-class tidal river; the Danube was a fresh-water stream, discharging into a tideless sea. The Humber drained 10,500 square miles, corresponding to one-fifth of the whole area of England; the Danube drained 300,000 square miles, or six times the whole area of England. Assuming the rainfall to be the same in both cases, the fresh water discharged by the Humber was only one-thirtieth of

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxviii., p. 472.

that of the Danube, and one-half of that of the Sulina mouth. The greatest effect on the Sulina bar was produced by the discharge of a great flood, which the Author gave as amounting to 4,500,000 cubic feet per minute; while the greatest effect in the Humber was produced by spring tides, which passed 132,000,000 cubic feet per minute, or thirty times the actual quantity, and sixty times the quantity relatively to the drainage areas. The dimensions of the Sulina mouth did not exceed 600 ft. in width and 20 ft. in depth, giving a sectional area of 12,000 square feet. The Humber at low water was 3 miles wide and 70 ft. deep, and had a sectional area of 680,000 square feet, or nearly sixty times as much as the Sulina, though discharging half the volume of fresh water. Those facts spoke for themselves—and, when it was considered how numerous the English harbours were, some idea might be formed of the relative value of tidal water and of fresh water, and of the importance of maintaining the tidal action of rivers unimpaired.

Captain Calver, R.N., F.R.S., through the Secretary, said, he should confine his remarks to the physical features of the locality under discussion, and to the various effects which had followed the construction of the artificial works. There could be but little doubt that, whether as respects its interior navigation, the amount of its discharge, or the character of its frontage both as to formation and position, the Author was essentially right in originally selecting the Kedrilles mouth of the St. George's channel for improvement in preference to the others, although that at Sulina was eventually adopted from motives of expediency. Though the entrance channel of the St. George was longer than that at Sulina, still, as the former occupied an advanced geographical position with respect to the coast on either side, and as its frontage was swept and kept comparatively steep by a littoral current—generally setting 1 mile per hour from north to south—it was quite clear, as the Author remarked, that the prolongation of works necessary to keep pace with new deposits would be less considerable there than at other mouths.

A difference of opinion existed as to the nature of the works needed at the mouth of a sea outlet such as that of the St. George, but that appeared to be the result of forgetting that it was a matter which embraced the question of protection as well as that of depth. If depth alone were needed, there was little doubt that a single pier on the southern side, curved, and pointing at its outer end in about an east and west direction—that in which the natural channels generally trended—would insure a fixed and deep channel along the face of the artificial work; but a pier so uncovered during

the prevailing winds, which were generally from the northward and north-eastward, would, in effect, be a dangerous reef under the lee of a vessel entering at such times, and a casualty would probably involve the loss of life as well as of property. The north pier, by 'covering' the channel, provided for that contingency, and its moderate prolongation beyond the head of the south pier also supplied shelter for a vessel directly she reached the entrance of the channel. A single pier in such a locality, with a northern exposure, would also be accompanied by the additional drawback of serving as a conductor to the sea undulation upwards to far within the entrance channel, and this would produce a shallower and more irregular navigation than that secured by the concentrating and covering effect of two piers. The proper outer limit for such works, whether at the Sulina mouth or otherwise, ought always to be determined by experiment, rather than to be allowed to depend upon opinion, and thus to involve the risk of mistake, to which the closest observers were liable. A cheap and certain way of doing that in a frontage of loose soil, would be to prolong the effect of the stream outwards by rows of piles driven sufficiently down and tied together for their own security, and, when effects were developed and certainty established, to draw the piles, and make use of them in the construction of artificial works over the same sites. Were some such simple tentative measure always adopted in cases of this order, much needless outlay would often be saved, and mistakes would be avoided.

Respecting the Sulina improvement, and the effects which had followed, but few remarks were needed. The banking up behind the south pier was the result of detritus discharged through the Sulina channel and deposited under shelter from the prevailing winds and littoral current, while the 'trend' of the outer part of that accumulation in a north-easterly direction was as evidently the result of the lash of the heaviest seas, which were those from a south-easterly quarter. To this fact, and to the lowering of the whole area north of the north pier, remarked upon by the Author, was due the north-easterly direction of the outer part of the channel, to which attention had been drawn in the discussion; it was due, in short, to the scouring stream from the river working in the direction of the steepest slope.

The Author remarked that:—"the works seem to have had the effect of greatly retarding the growth of the 24-ft. bank and of the 30-ft. bank, as the advance of those banks eastward—to the north and south, and in front of the piers—during the ten years ending November, 1871, was only 44 ft. per annum, whereas during the

twenty-eight years immediately previous to the beginning of the works, the same contour lines advanced at the rate of 97 ft. per annum."[1] By that was apparently meant, not that the same amount of matter discharged from the Sulina did not accumulate in front of its entrance, but as the accumulation was projected into deeper water, the contour lines embracing the accumulation were closer than formerly; but surely the same effect would ultimately have followed even without artificial works as the accumulations in the course of years advanced eastward, and their seaward slopes were kept increasingly steeper by the littoral current. The Author also attributed the erosion to the north to the rebound of the sea against the north pier during heavy northerly, and north-easterly gales, but such a cause would seem to be too local to produce so great an effect. It could be imagined that the disturbance might produce a lowering in the immediate vicinity of the work, but it would be powerless to effect much alteration at a considerable distance from it. Might it not be due to the suspension of material by the cross-sea, and its transferrence to deeper water by the under-tow, or under-current, which always existed in such bights or embayments when the water within them was forced above the normal level by the pressure of on-shore gales?—an effect which was often observed along the shores of the eastern sea-board of England. However that might be, it was suggested as a possible reason for the fact recorded by the Author.

If the history of the improvement of the Sulina mouth of the Danube by artificial works afforded no clue to the proper treatment of the rivers of Great Britain—which were altogether of a different character—still it showed that success was sure to follow from a close observation of physical features and effects, and from the adoption of means to assist the operations of nature instead of opposing them.

Colonel J. Stokes, C.B., R.E.—in the absence of Sir Charles Hartley—in reply, said, he would, in the first place, refer to the remarks of Sir John Coode with regard to the direction and length of the piers. Great importance was attached to the direction of the deep channel to the north, and with that view it was considered preferable to have made the south pier longer than the north pier. It must, however, be borne in mind that when the works were planned the bar extended across the mouth where the present channel was now shown. There was formerly a slight deflection in the centre which was used as a channel. The Author's object was that the

[1] *Vide* ante, p. 215.

river should eventually take its natural course to the sea through that bar. His first consideration was so to place the piers as to give the navigation the greatest amount of shelter in entering, and that was gained by leading the river out on that course. If he had thrown out the south pier in advance of the north pier, the effect would have been to bring it to leeward of every ship that entered with the prevailing wind. Colonel Stokes need not point out that that would have constituted a danger to the navigation instead of giving it relief and shelter. By giving the north pier a considerable projection beyond the south pier, as soon as a vessel entering came under the shelter of the north pier, and at the moment when she began to feel the greatest strength of the current, the pier protected her from the waves, and prevented her from losing her way in the broken water on the bar. In such a case the value of the projection to vessels could be easily imagined. Had the south pier projected beyond the north pier, a further injurious effect would probably have resulted. The current would have been met by the seas running in under the prevailing winds, a considerable amount of material held in mechanical suspension which now escaped to the south would have been deposited, and very likely the present deep channel would not have been obtained.

The channel which had resulted from the construction of the piers took its course straight to seaward. There had always been a deeper channel to the northward, which Colonel Stokes would presently account for; but, in the course of the discussion, the question had been put as to the amount of littoral current, and also as to what there was to show that there was a littoral current at all. He thought the existence of the bank to the south of the Sulina mouth, and the fresh formation of shoals to the south of each of the other delta embouchures, after every flood, must show the existence of a constant current, taking the bulk of the new water to the south, and thereby, as it met the stiller water, causing a deposit of silt in that direction.[1] If there was no littoral current to turn it to the south, the silt would be thrown down across the front of the river. Its existence was ascertained before the works were carried out, the Author having instituted a series of observations with floats to test the amount of the current, the result of which proved that there was a decided current across the mouth of the river, which extended as low as 4 ft. below the surface in a depth of 10 ft. The depth on the bar at that time was

[1] *Vide* "Mémoire sur les travaux d'amélioration exécutés aux embouchures du Danube, par la commission Européenne instituée en vertu de l'article 16 du traité de Paris du 30 Mars, 1856," page 35.

8 ft. or 9 ft. It was also shown that during calms, northerly, and north-westerly winds, there was a considerable littoral current from north to south, and during southerly, and south-westerly winds, a surface current from south to north; but it was so feeble as to indicate that the force of the wind had but just overcome that of the current from north to south. In strong westerly winds there was a counter current setting in about 5 ft. or 6 ft. below the surface; but this was not observed during the northerly winds, which so generally prevailed at the mouth. The Kilia branch, fifteen miles north of the Sulina, discharged two-thirds of the water of the Danube into the Black Sea, the whole of which set past the mouth of the Sulina. Seamen found a very constant current of from $\frac{1}{2}$ knot to 1 knot per hour setting from the north to the south along the coast of the delta. Colonel Stokes therefore thought it established that there was a littoral current generally from north to south across the Sulina mouth. It had been remarked that the existence of the deep water channel to the north was inconsistent with the current to the south. He really thought that was not the case. The river as it issued forth into the sea was diverted during the greater part of the floods to the south, and threw down the banks there seen, which—owing to the duration of the floods—helped by occasional southerly winds checking the current to the south—gradually extended to the north. The prevailing northerly winds, however, constantly broke down the edge of that bank during the autumn and winter, and gave a good channel to the north of it. The longer that action took place the more directly east did the best channel run out, and it was only again found to the northward after fresh floods had created anew the south bank. That phenomenon had been so often witnessed by the Commission and its Engineer as to have been assumed as the admitted law of the Sulina mouth, which thus maintained its depth by the simple action of the trained river current on the one hand, and the littoral current and sea waves on the other, without any recourse to dredging being necessary.

As regarded the extension of the south pier, no doubt the relative lengths of the two piers, as originally projected, were not an entire success. In certain years—about every fifth year—there were hardly any floods in the Danube, and then the force of the current between the piers was not more than $\frac{1}{4}$ knot or $\frac{1}{2}$ knot per hour. During those periods of slack water, shoals were formed in consequence of the water losing its force as soon as it escaped the parallelism of the piers. The Author had therefore recommended the Commissioners to prolong the south pier 450 ft., as stated in

the Paper. The north pier was thus left 150 ft. longer than the south pier, in order not altogether to lose the protection which the projection of the north pier gave to shipping. The result had proved successful, for in slack water the shoal was thrown down outside the piers as it was during floods; and in a very short time it was similarly broken down by the action of the waves, and the expectations of the Author when recommending the prolongation had thus been completely fulfilled.

Colonel Stokes considered it desirable to notice the following remarks made by Mr. Brooks, in the course of the present discussion:—"When the question of the Danube works was formerly before the Institution, he had made certain recommendations based on the case of the harbour of Swinemunde, in the Baltic, and he was glad to see that, to a certain extent, they had been carried into effect, and that, from the line on which the piers were being constructed, there was a probability of their being kept in the direction which had been given to those at the harbour of Swinemunde, in the Baltic. If the additional works were carried out as he then recommended, the result would be that the current of the ebb would have greater effect in carrying away the deposit which was now taking place in advance of the entrance to the port."[1] Colonel Stokes could only say that the principle of the original design of the Sulina piers had not been departed from. He would further observe that in the abstract of the minutes of the discussion which followed the reading of the Author's previous Paper, Mr. Brooks is stated to have said that:—"the improvement of Dublin Harbour was not a case in point, because in that example the action was mainly due to tidal water inclosed by the piers. A parallel case, however, existed in the Baltic, a tideless sea, in the works for the improvement of the Harbour of Swinemunde, where only a single pier to the east of the entrance had been run out. It had been constructed with its concave face exposed to the action of the debouching waters, and was subjected, also, to the scouring action of the littoral current, which set from west to east, or directly on the concave face of the pier. There was no second pier at Swinemunde, but mooring, or warping piles were placed at intervals along the west, or convex shore. The result was, that a permanent deep-water channel, having a depth of 18 feet, was established alongside the pier, and all detritus was swept past the pier head to the eastward. The same principle ought to have been applied at the mouths of the

[1] *Vide* ante, p. 226.

Danube. He thought the system of forming piers concave to the current of the ebbing water, and also presenting their concave side to the direction of the littoral current, was preferable to the principle adopted in the works at the mouth of the Sulina. It would have been better to have formed the pier from the south side of the mouth of the river, so as to compel the effluent water to range along it."[1] As far as Colonel Stokes remembered that discussion, the recommendation of Mr. Brooks was—as stated in that abstract —founded on the assumed fact that the Swinemunde mouth of the Oder had been improved by the projection of one pier only. The Author, on that occasion, in his reply distinctly stated that he "knew from personal observation that there was a west as well as an east pier at Swinemunde, and that each of these piers had a width of 60 feet at the water-line;"[2] and he also furnished the Institution with a copy of the Prussian Survey of 1858 (vol. xxi., Plate 10), upon which the two piers as constructed were delineated. Colonel Stokes, from his personal knowledge of the treatment of the Oder, could confirm the Author's testimony as detailed in the abstract of the discussion of the previous Paper, that the improvement of the Oder was attributable to the existence of the two piers. The experience which had been gained at Sulina since the completion of the provisional works fully confirmed the soundness of the theory on which they were designed, namely, that in order to maintain an improved depth at Sulina, two piers should be run out parallel to each other near their extremities, in the best direction for the continued prolongations which would hereafter be necessary to perpetuate the improvement.

With respect to the alleged clearness of the waters of the Danube, Colonel Stokes thought there had been some misapprehension. The fact was, the water was extremely turbid, and only under certain circumstances was it clear, as, for instance, after the subsidence of floods. The greatest depth was obtained when a strong current prevailed with clear water. That combination did not occur frequently; but when it did it was under the following circumstances:—The whole course of the Danube for 100 miles above the sea was studded with large lakes lying on either side of, and in connection with, the river. During very high floods they were filled; and, there being no current in them, they acted as reservoirs and settling beds for the filtration of the water. The mud being deposited in them, as the river fell below their level, the clear

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxi., p. 296.

[2] *Vide* Ibid., p. 504.

water ran out, thereby maintaining a strong current in the channel. It was only under those exceptional circumstances that sometimes a large amount of clear water was running out of the mouth.

From some remarks made, he was under the impression that there had been also a misapprehension to the effect that a certain portion of the water had been diverted from the Sulina branch. The contrary was the case, as rather more water passed down it now than formerly. Works had been undertaken to remove the shoal which obstructed the head of the channel at the St. George 'Tchatal,' or fork, where the Sulina left the Toultcha branch. This point had not been touched upon in the Paper; but a groyne had been thrown out from the south lip, projecting considerably into the St. George's branch, thus embracing a portion of its waters, which it turned into the Sulina. By the construction of another groyne on the north side, the entrance into the Sulina was contracted in width, and deepened by the scour on the bottom, so that, instead of the water flowing away through a channel 10 ft. deep, it now filled a channel which, though narrower, was 17 ft. deep at low water; and consequently a rather larger quantity passed down the Sulina than previously to the execution of those works.

As regarded the proportion of cement used in the manufacture of the concrete, Colonel Stokes had no information which he could add to that contained in the Paper and the Tables in the Appendix.[1]

As regarded the concrete trial blocks, some of which, as stated in the Paper, had succumbed to the first gales which followed their construction, he remembered that they were damaged by the sea before the concrete of which they were composed had had time to set hard enough to withstand the constant wash of the waves at the foot of the temporary timber dams in which the concrete had been thrown in a liquid state. The foundation of loose rubble on which those isolated masses of concrete were founded was also at the same time beaten down by the waves. Hence the blocks were not only partially disintegrated but they were undermined as well, and it was a consideration of those circumstances which induced the Author to increase the proportion of cement, as he had described in the Paper, and to carry on the consolidation of the piers in one continuous line, as a further precaution against the scouring effects of heavy seas, instead of simultaneously at various points, as he had once thought of doing, with a view to gain time.

With reference to the question asked about the formation under the 'pierre perdue,' shown in Fig. 8 (Plate 28), Colonel Stokes might

[1] *Vide* ante, pp. 221 and 222.

say that it was the natural bed of sand on which the whole of the work reposed. There was no artificial material underneath the stone. The appearance of such an artificial formation in the sections was due to the scouring away of the river channel, and the consequent slipping down of the stone revetment which protected the heart of the foundation, as it was originally intended to do. Without that revetment the work would not have stood, as the scour round each pile as soon as it was driven was very great, and only arrested by the immediate throwing down of stone.

Some question was raised with regard to the slope. The slope of $2\frac{1}{2}$ to 1 was on the outer, or sea side of the work; that of $1\frac{1}{2}$ to 1 on the river side. Sir John Coode had inferred, from the 'pierre perdue' having subsided only 3 ft. or 4 ft., that the force of the waves at the Sulina entrance could not be very great. Colonel Stokes would point out that the effect of 3 ft. or 4 ft subsidence, in fact, meant 3 ft. or 4 ft. every winter. Holes made by the scour were constantly filled up, otherwise the whole work would soon have been swept away. Round the extremity of the pier this subsidence was often as great as 12 ft. or 14 ft., until the stones formed the slope which enabled them best to resist the batter of the sea, whilst they became packed against the piling like solid rock. It was also to be remarked that most of the force of the sea was eluded by the piers, owing to the lowness of their profile. During the heaviest gales the level of the sea was generally so much raised by the damming up of the river, that the sea made a clean sweep over the north pier, the greater part of which was generally quite hidden from view during severe gales. The force of the waves at such times might be inferred from the fact that blocks of concrete weighing 20 tons had been hurled from the platforms on which they were standing 4 ft. above the sea level; and oak timbers, 12 in. by 6 in. in cross section, had been broken across the grain.

As to the probable extension of the Sulina piers at a future period, neither the Author nor the Danube Commissioners had shut their eyes to the fact that eventually the piers would have to be prolonged. It was probable that the delta of the Kilia branch would eventually be pushed out to such a distance that the littoral current would pass the Sulina at a greater distance seaward, and that the piers must be extended so as to follow it; but at present there were no indications of such a result. On the contrary, the beneficial effect of the works for the last three years had been more striking than at any previous period. Since the prolongation of the south pier had prevented the formation of the bank between the two pier heads there had been no symptom of deterioration of the channel.

A glance at the survey made in March, 1873 (Plate 27), would show that there was now a channel of 20 ft. in depth straight out to sea, and north of the 20 ft. line a channel of 21 ft. Vessels had passed out during the spring of the current year drawing 20 ft. 3 in.

Colonel Stokes hoped the Meeting would allow him on this occasion, which might be the only one he should have of addressing them, to say a word with regard to the Author—the man himself who had so successfully designed and superintended the works which had been described in the Paper—a word which he wished the more to say, as he had worked with him for fifteen years, and knew his worth. The Author went out at the request of a body of whom six out of seven were foreigners, whose wish it was that an English Engineer should be employed on those works. Colonel Stokes, knowing the excellent qualities of the Author, recommended him to be the Chief Engineer of the Commission. Shortly after the Author's arrival on the Danube, another Engineer was sent out by one of the Governments represented in the Commission to advise their Commissioner, and report on the river. This Engineer had the advantage of speaking a language understood by all the Commissioners, while the Author arrived with only a scanty knowledge of French and none of German, and he could not, therefore, make himself understood by those who were to be his employers, and who had to dwell upon the merits of his plans. Colonel Stokes could scarcely conceive a more difficult position for a man to be placed in, considering the jealousies which always occurred on those occasions. Under those circumstances, the Author was urged to report to the Commissioners before he could collect what he considered sufficient data for his guidance. The attempt to force from him a premature opinion was successfully resisted; but it naturally affected his proceedings, and he had at the last moment to launch his report after that of the other Engineer had been some time before the Commissioners, many of whom were biased in its favour, and had had it carefully explained to them; but so sound and moderate were the views taken by the Author, and so ably were they stated, that they prevailed. In spite of the difficulties thus experienced at the outs t. by the end of two years the Author had completely won the confidence of the Commissioners by the ability and modesty which he displayed. During his long sojourn on the Danube he had, by his high integrity, strict justice, and delicate sense of honour, gained the esteem and affection of every one with whom he had been brought in contact—not excepting those who originally were opposed to him.

May 20, 1873.

T. HAWKSLEY, President,
in the Chair.

The following Candidates were balloted for and duly elected :— George William Keeling and John George Mair, as Members; William John Fraser, Arthur Henry Heath, Lowis Jackson, Elias William Jones, John Milton Lewis, Frederick Harry Mort, Stud. Inst. C.E., George Edward Ormiston, Robert Hunter Rhind, George Henry Roberts, Frank de Mierre Turner, George Waller Willcocks, Francis Windham, Stud. Inst. C.E., and Sir William Wright, as Associates.

It was announced that the Council, acting under the provisions of Sect. III., Cl. VII., of the Bye-Laws, had transferred Alexander Richardson Binnie, Richard Henry Brunton, and Edward Harry Woods, from the class of Associates to that of Members.

Also, that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution :— Charles Arthur Friend, Edward Fyfe Griffith Griffith, Herbert Septimus Harington, Frederick Sharp, Harry Scott Taylor, Charles Tickell, Augustus Bythesea Todd, Claude Vincent, George Edward Vint, and George Kempthorne Watts.

The discussion upon the Paper, No. 1,367, "On the Changes that have recently taken place along the Sea Coast of the Delta of the Danube, and on the Consolidation of the Provisional Works at the Sulina Mouth," by Sir C. Hartley, was continued throughout the evening.

May 27, 1873.

The Session was concluded by a conversazione, which was given by the President and Mrs. Hawksley, in the West Galleries of the Annual International Exhibition Buildings at South Kensington, by permission of Her Majesty's Commissioners for the Exhibition of 1851. The section of the Exhibition opened to the visitors included the machinery in motion—this year devoted to the Manufacture of Silk Velvet, and to mechanical processes involved in the production of Food—and the British and foreign paintings. Some objects from the Scientific Inventions Court, and from other parts of the Exhibition, were likewise transferred for the occasion to the West Galleries. In addition to the members of all classes of the Institution, invitations were sent to, and were accepted by, a numerous circle of distinguished men of science and others; and in every case the card of invitation admitted a lady.

# APPENDIX TO ANNUAL REPORT.

## MEMOIRS.

Mr. NATHANIEL BEARDMORE, the second son of Joshua and Marianne Dorothea Beardmore, of Nottingham, was born on the 19th of March, 1816. His father removed shortly afterwards, first to London and then to Devonshire, where the childhood and youth of young Nathaniel were principally spent. His culture, both moral and mental, was carefully attended to by his parents, and he was particularly indebted to the talent and assiduity of his mother, who especially superintended his early education, and even to some extent anticipated the schoolmaster by teaching him the rudiments of Latin and Greek. In 1826 he attended with his brothers a day-school at Chudleigh, and subsequently the Devonport Grammar School. Here his powers of observation were developed under the careful instruction of the head master, the Rev. H. Greaves, with whom for some years he resided. At this period the mechanical bent of his mind became noticeable; and it is related that he designed and made a working model of a steam traction-engine, to the delight of his brothers and sisters. At that time traction-engines had only just been invented. Amongst his contemporaries at this school were Dr. Colenso and Mr. Charles Greaves, M. Inst. C.E.

In 1831 he commenced his professional education. In the first instance he was placed with the late Mr. George Wightwick, an architect in Plymouth, for instruction in drawing, at the expiration of which he was articled for five years to the late Mr. James Meadows Rendel (Past President Inst. C.E.), then a resident in the same town, and rising rapidly into practice and fame. Mr. Beardmore, as Mr. Rendel's first pupil, had an excellent opportunity of acquiring a thorough knowledge of his profession. He was employed on the surveys of the Exeter and Plymouth railway, of the new road to Kingsbridge, and of the floating bridge across the Itchen, at Southampton, as well as upon the drawings of the proposed suspension bridges at Clifton and at Montrose, and the Government works in Plymouth Sound and Devonport.

At the expiration of his pupilage, in 1838, Mr. Beardmore took an office in London, and made a survey of Effingham parish, in the county of Surrey. He was also engaged on the branch line of the Brighton railway to Portsmouth, and during the autumn was employed by Mr. Rendel on the Parliamentary surveys for a proposed railway between Exeter and Plymouth across Dartmoor. Subsequently he accepted an offer of partnership from Mr. Rendel, who removed to London, and left Mr. Beardmore in charge of the office and business in Plymouth.

In 1841 Mr. Beardmore married Mary, eldest daughter of the late J. F. Bernard, Esq.

The principal works which then occupied Messrs. Rendel and Beardmore in the vicinity of Plymouth were the improvement of the Devonport Water Company's service reservoirs and distributing mains, for the supply of water to the town, the dockyard, and the public departments; the construction of the Millbay Pier, in a small tidal basin at the top of Millbay, Plymouth; the preliminary surveys for the South Devon railway, and marine and riverain works for public companies, the Admiralty, and other Government departments.

In 1843 Mr. Beardmore left Plymouth for London. In 1844 he was engaged on a project for improving the water-supply to Glasgow, and superintended the Parliamentary surveys for the Glasgow Gravitation Water Company. This project embraced the construction of a large reservoir in the valley of the Avon, at Gilmerston, about 24 miles south of Glasgow, from which the water was to be conveyed by an aqueduct to a depositing reservoir at Cathkin, and thence into the city by pipes. In the spring of the following year, however, the Company was dissolved and the scheme abandoned.

In 1845 he went to Spain, and made an inspection of the country from the harbours of Aviles and Gijon—passing through the coalfields of the Asturias—to Leon and Madrid, preparatory to laying out the line for the proposed Royal North of Spain railway. The construction of this work was not at that time carried out. Parenthetically, it may be noted that his grasp of the topographical features of a country and of its resources, from an Engineer's point of view, was exceedingly keen, and he worked with great rapidity, especially at levelling and surveying—a characteristic which was much appreciated in his younger days. On his return to England he was engaged in preparing plans for the proposed Ipswich, Norwich, and Yarmouth railway; and in short, during the rest of that year, and in 1846, he was, like all the rest of the profession,

almost exclusively occupied on behalf of, or in opposition to, railway projects.

Mr. Rendel having been retained by the Edinburgh Waterworks Company as their Consulting Engineer, Mr. Beardmore was engaged with him in reporting upon the improvement and extension of their works, and took an active and prominent part in surveying and designing the extensive works included under the Bill of 1846–47. The Act was obtained, and the works were eventually carried out under Messrs. Rendel and Beardmore by Mr. J. Leslie, M. Inst. C.E., of Edinburgh, between the years 1847 and 1852. They consisted in the raising of the original, or Glencoe, reservoir constructed by the late Mr. Jardine, C.E., about 1823, and the construction on the Pentland Hills of five other store and compensation reservoirs, one of which was 85 ft. deep, the aggregate additional storage thereby provided being about 600,000,000 gallons; the collection by branch pipes of the waters of numerous springs on the north side of the Pentland Hills; and the conveying of that water to Edinburgh by a masonry aqueduct of upwards of 4 miles in length, and through 5 miles of iron pipes.

By mutual consent Mr. Beardmore's partnership with Mr. Rendel terminated in 1848. During that time he was engaged on the Birkenhead Docks project, which attracted so much attention at that period, and also on extensive drainage operations on the Nene, Wyze, Plym, Ouze, &c.; and he was connected, more or less directly, with the improvement of the supplies of water to several of the larger towns in the north of England.

But the works for the improvement of the navigation and drainage of the river Lee were those upon which he was most continuously employed. He was introduced to these works in 1847, by his connection with Mr. Rendel, and became sole engineer to them in 1850, when an Act of Parliament was obtained sanctioning the thorough improvement of the river. From that time he devoted himself with untiring energy to carrying out the new works, and, in 1855, removed from Westminster to Broxbourne, in Hertfordshire, as the most central situation for their supervision. In 1854 Mr. Beardmore contributed a Paper to the Institution, giving a description of the improvements executed on the First Division, or Tidal portion of the River,[1] which was followed, in 1858, by a Paper by the late Mr. Richard Carden Despard, M. Inst. C.E., then his chief assistant, on those executed in the Second Division.[2]

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xiii., p. 241.

[2] Ibid., vol. xvii., p. 386.

The navigation being one that in places utilizes the old river channel, and, in other places, is worked through special cuts, has, in consequence, in many parts, the whole of the floods of the valley to carry off, and hence as the difficulties of navigation were more due to excess than to want of water, a considerable amount of engineering skill was required to construct durable works capable of being economically managed under these conditions. In his report of 1859 Mr. Beardmore states that previously to 1850 "the locks and bridges were in the last stage of existence;" and some idea of the task which he undertook may be gathered from the fact, that the works executed under his superintendence comprised the rebuilding of thirty-eight bridges, twelve locks, six tumbling-bays, the formation of five cuts, and the obliteration of four locks and two tumbling-bays.

In addition to his engagements on the river Lee, Mr. Beardmore, in 1855, laid out the Colne Valley and Halstead railway, which he subsequently constructed as Engineer-in-Chief, Mr. J. H. Barnes, Assoc. Inst. C.E., acting as Resident Engineer. About this time, also, he was much engaged on the Liverpool and Garston Extension railway; and, in 1859, he prepared plans and estimates for a proposed line of railway from Norwich through Aylsham to Cromer.

Mr. Beardmore's "Manual of Hydrology"[1] is a book too well-known to the profession to require any special description. In early years he had found by personal experience how much labour might be saved by the systematic use of tables in the computations daily required by the hydraulic engineer; and many of the tables it contained were originally prepared for private use. The first edition was published in May, 1850, under the unassuming title of "Hydraulic Tables."[2] Its compilation cost him much mental labour, most of which was performed in the quiet midnight hours, when the professional work of the day was ended. The estimation in which these tables were held by competent judges, and the manner in which they were appreciated by the profession in general, was shown by the fact that in a very short time (Sep-

[1] "Manual of Hydrology; containing—I. Hydraulic and other tables; II. Rivers, Flow of Water, Springs, Wells, and Percolation; III. Tides, Estuaries, and Tidal Rivers; IV. Rain-fall and Evaporation. By Nathaniel Beardmore, Civil Engineer. London, 1862."

[2] "Hydraulic tables, to aid the calculation of water and mill power, water supply, drainage, and navigable rivers; with synopsis of rainfall in Great Britain, &c. 8vo. London, 1850."

tember, 1851) a second edition was called for. This edition, which was considerably enlarged and amended, was immediately printed and published.[1] It was sold out nearly as quickly as its predecessor, and the work soon became very scarce; but the Author, instead of reprinting, was anxious still more to improve, arrange, and extend its contents, which had been compiled originally rather in the form of notes than as an exact treatise. Much time was spent in making the necessary calculations, and in collecting and collating additional data, Mr. Beardmore being in correspondence with scientific men in all parts of the world, so that it was not until 1862 that the "Manual of Hydrology," as it now stands, was placed before the public. It is to be feared that English engineers are with justness reproached with their indisposition to communicate to others the result of their investigations and experience. By the publication of the work in its complete form Mr. Beardmore proved himself an honourable exception to a general rule, and earned the gratitude of his professional brethren. "It is a most invaluable work," wrote a friend; "scarcely more valuable, indeed, to people of your own profession than as affording a vast amount of admirably condensed information on a wide range of subjects in which almost every one is interested. The amount of knowledge it displays, the remarkable skill in condensing it, and the labour and research it must have cost, are all unique and all worthy of each other and its Author." Few men can be found who, apart from the mere bread-winning exercise of their professional abilities, have laboured more assiduously to gather, improve, certify, corroborate, and condense those laws and rules which are connected with hydraulic science, than the late Mr. Nathaniel Beardmore.

As may be expected, the publication of the successive editions of the "Manual of Hydrology" greatly extended its Author's practice, and many important questions in connection with hydraulic matters were submitted to him both at home and abroad. In 1852 he went to France and inspected the Lyons Waterworks, at the same time making interesting observations on the rivers Rhone, Saône, and Loire. In the following year he went to Turin, having been requested to report on the water-supply to that city. In 1865

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[1] "Hydraulic tables, to aid the calculation of water and mill power, water supply, and drainage of towns, and improvement of navigable rivers; together with the properties and strength of materials; useful numbers and logarithms; also tide tables for 1852, 1853, 1854; tidal constants; with various phenomena of tidal rivers. 8vo. Plates. London, 1852."

he visited Russia, and, after conference with M. Dessemond, prepared plans and designs for giving a better water-supply to the cities of Moscow and Odessa.

In and subsequently to 1856, he was frequently consulted by the Public Works Loan Commissioners, and appointed to report on various railways, harbours, and waterworks. In 1860 he became Engineer to the Hon. Court of Commissioners of Essex Sewers through the recommendation of Messrs. Walker and Burges, who, during the time they held the office, had constantly consulted with him on various matters connected therewith. Mr. James Walker, Past-President Inst. C.E., of that firm, in 1862 made proposals of partnership to Mr. Beardmore on equal terms with himself and Mr. Burges, and in September the deed was signed; but the partnership was abruptly terminated by Mr. Walker's sudden death on the 8th October in the same year.

On the occasion of the great flood at Sheffield, owing to the bursting of the Bradfield Reservoir, Mr. Beardmore was appointed by the Home Secretary, together with Mr. R. Rawlinson, M. Inst. C.E., Government Engineer and Inspector, to examine and report on the probable causes of the disaster.

In 1866-67 Mr. Beardmore gave evidence before the Royal Commissions upon inquiry into the best means of preventing the pollution of rivers and on the water-supply to the metropolis and other large towns.

His opinion in cases of arbitration was much sought, and his ability in giving evidence was considerable. As early as the year 1851 he was appointed arbitrator in the prolonged case of the East Anglian *v.* Burge, again, in 1853, in the case of the Ipswich Dock Co. *v.* Byles; and he subsequently acted frequently in that capacity.

He was consulted in 1867 on the proposed new bridge over the Thames at Caversham, above Reading, which was subsequently designed and constructed under his superintendence, in conjunction with Mr. Woodman, the borough surveyor; it is a lattice girder bridge supported on cast-iron piles with brick abutments.

Next to the river Lee the river Thames claimed most of his attention, and he knew well all parts of it from its source to London. From the year 1849 he was much occupied in gauging, and making other investigations in connection with hydrological phenomena. After 1859 he was occasionally consulted by the Conservancy Board, and, in 1866, gave evidence before the Parliamentary Committees on the passing of the Thames Navigation Act. In the following year he was requested, together with

Mr. Stephen William Leach, M. Inst. C.E., the Conservators' Engineer, to report to the Board on the general state of the upper part of the river, and to define the new works more immediately required for the effective working of the above Act. Since the date of that report he acted as Consulting Engineer to the Thames Conservancy Board, and in that capacity reported upon Mr. Leach's plans and designs for the new works at Bell weir, Hambledon and Benson locks. Teddington weir was the last work he reported upon; but during the whole of the year 1872, up to the time of his death, he was engaged, in conjunction with Capt. Calver, R.N., Assoc. Inst. C.E., in an inquiry as to the state of the river at Richmond, with the object of reporting upon the advisability of placing a lock below that town in order to keep up the water, or suggesting other means for removing the complaints of the inhabitants of Richmond, and of other places on that portion of the river.

At an earlier period Mr. Beardmore entered into partnership arrangements with Mr. John Hickman Barnes, his chief assistant, and former pupil; and with his eldest son, Mr. Nathaniel St. Bernard Beardmore, Stud. Inst. C.E., who had been for some years in his office.

Mr. Beardmore took out a patent in the year 1848 "For certain improvements in founding and constructing walls, piers, and breakwaters," [1] by the use of wrought-iron, cellular construction, and the extension of girder forms of structure. This invention was also specified as being applicable to the construction of fireproof flooring for warehouses, and for other buildings where great strength was required, and it was described as a combination of wrought-iron plates with a filling of concrete, its principal advantage for building purposes being its greater lightness than the ordinary structure of cast-iron beams with half-brick arches.

Amongst other invited competitors he contributed a design for the main drainage of the metropolis. His plan comprised an aqueduct sewer, with a street-road over it, extending from the extreme west of London to the Thames at Barking Creek.[2] The specification of Mr. Beardmore's project was ordered to be printed and circulated amongst the members of the Corporation, and, probably furnished, in common with other competitive plans laid before the Commissioners of Sewers in 1849, some of the prin-

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[1] *Vide* "Newton's London Journal" for the year 1849. Vol. xxxiv., p. 73.

[2] *Vide* "The Morning Chronicle," Oct. 1st, 1850, and "The Builder," Oct. 12th, 1850.

cipal features of the works now in operation. In the same year he wrote a pamphlet letter addressed to Viscount Ebrington on proposed modifications and extensions of the water-supply to the borough of Plymouth. In 1851 he contributed, by request, the article on Drains, Rivers, and Water Supply, to the "Westminster and Foreign Quarterly Review."[1]

Mr. Beardmore took great interest in several branches of science, and more particularly in those which had an immediate bearing on his professional pursuits. Being one of the members, he constantly availed himself of the opportunities for social intercourse which the Smeatonian Society afforded; and he also attended the gatherings of the British Association for the Advancement of Science, as well as those of the Canal Association, as often as his other avocations allowed.

He was one of the earliest supporters of the Meteorological Society, of which he became president in 1861. He was also a fellow of the Geological, Royal Geographical, and Royal Astronomical Societies. In referring to the last named of these, it may be mentioned that practical astronomy was one of the earliest studies to which he was attracted.

It is related that during his pupilage the construction of a Newtonian telescope became a great feat of ambition. A brother engineer, who shared to some extent his pursuits, remembers well the perseverance that young Beardmore displayed in constructing the specula. The metal, the moulds, the melting and mixing, were of course essential, so also the grinding and polishing. Failures were numerous, and many a night were these operations carried on until morning hours with crucibles on a kitchen grate; the landlord of his lodgings being pressed into the service with a pair of bellows, the unflagging movement of which was absolutely necessary to obtain the melting point for the amateur, whose zeal became shared if not comprehended by his veteran assistant of seventy.

Throughout a life of unremitting toil, with the exception of occasional attacks of rheumatism, he had enjoyed comparatively good health, but at length the continuous strain of mental exertion began to tell on his physical frame. In the spring of 1870 he lost the sight of one eye after an attack of inflammation. This trial he bore with the patience and resignation which he displayed throughout his illness. Towards the close of the same year his health further gave way, and henceforth, though still able to take

[1] *Vide* "The Westminster and Foreign Quarterly Review" for January, 1851, No. 107, and No. 92, page 368.

an interest, and even a part, in his business, he suffered much nervous exhaustion. In the spring of 1872 he appeared to rally, and was able to enter on his professional engagements with much of his former animation; but in August he was unexpectedly attacked with congestion of the lungs, and died on the 24th of the same month, in the fifty-seventh year of his age.

Possessed of a sound and practical judgment, an enthusiastic love for his profession, an untiring zeal and perseverance, together with a uniform kindness and fatherly spirit to those under him, Nathaniel Beardmore was highly esteemed by his professional brethren and beloved by all. His strict integrity and honour threw a lustre on all his business engagements. In private life his habits were simple; he disclaimed all ceremony, and was of a reserved and retiring disposition, but was ever ready with kind advice both professionally and privately. Nor was his assistance confined to precept. No man was more genuinely or unobtrusively generous. Some noticeable traits in his character are ably described by a friend who writes, "I do not know any one who unites the same qualities that were united in him. High-minded, generous, and genial, and with all this so much practical sagacity and insight into the real and relative importance of things in this world, that one might always consult him with profit."

His ready humour and originality rendered him very popular in society, and his courteous hospitality will be long remembered. He had a high appreciation for art, and a decided talent as an artist, and has left many enduring reminiscences of his travels in effective sketches, which he had a power of executing with wonderful rapidity.

Mr. Beardmore was connected with the Institution of Civil Engineers for thirty-four years. In 1838 he entered as a Graduate, and soon afterwards designed a double telescope theodolite, a description of which he laid before the Institution.[1] In 1846 he was elected a Member, in 1854 a Telford Medal was awarded him for his "Description of the Works executed on the River Lee,"[2] and in 1862 he became a Member of Council. He frequently attended the meetings, and took part in the discussions, and, always speaking to the point, was listened to with attention.

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Mr. DAVID REID EDGEWORTH, the fourth son of Mr. Francis Edgeworth, was born at Edgeworthstown, Longford, on the 14th of

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. i., 1841, p. 96.

[2] *Vide* Ibid., vol. xiv., p. 172.

April, 1842. He was a nephew of the authoress, Maria Edgeworth, and a grandson of R. L. Edgeworth. Educated at home with his three brothers till his fourteenth year, he entered the Royal Navy as a midshipman in the summer of 1855, coming out first at the entrance examination. After a service of a year and a half, partly spent in H.M.S. 'Firebrand' at the Crimea, he left the Navy, disliking the monotony of the life. He was then articled to Mr. G. W. Hemans, Vice-President Inst. C.E., and on the termination of his pupilage, in 1860, he was employed by Mr. Hemans on various lines of railway in Ireland, being successively Assistant Engineer for one year on the Longford and Sligo railway, then for two years Resident Engineer on the Streamstown and Clara railway, next, for one year in the same capacity on the Athenry and Ennis railway, and, afterwards, for a year and a half District Engineer on the Enniskillen, Bundoran, and Sligo railway. Towards the close of the year 1865 he commenced business on his own account, and latterly became interested in the reclamation and cultivation of lands on the coast of Wexford. He died on the 14th of October, 1871, from bronchial inflammation, induced by exertions during bad weather, while inspecting reclamation works, which his constitution was too delicate to resist.

Mr. Edgeworth was elected a Member of the Institution on the 4th of February, 1868. He was a man of energy and ability, possessed some of the mechanical ingenuity for which his grandfather had been remarkable, and invented a machine for rapidly measuring distances. His keen intellect was incessantly on the alert, and his loss was greatly felt by all those connected with him either by business or social ties.

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Mr. JOHN MORTIMER HEPPEL was born at Taplow, Bucks, on the 23rd of December, 1817. He was the eldest son of Mr. George Hastings Heppel, a proprietor of paper mills in that neighbourhood. His childhood was passed at the house of his grandfather, at Bayswater, where he remained until he reached the age of six. He then returned to his parents, who in the meantime had removed to London, where his father had been elected common councilman for the ward of Broad Street. When nine years old he was sent to Merchant Taylor's School, and on leaving it at sixteen he attended classes at the London University, where he gained a prize for natural philosophy.

Mr. Heppel commenced his engineering education at the age of seventeen, under Mr. G. P. Bidder, Past-President Inst. C.E., at

the West India Dock Quay, and subsequently entered the workshops of Messrs. Rennie as a pupil, remaining there for two years. After having been employed on the Northern and Eastern, and several other English railways, he entered into partnership with Mr. Moser, a German gentleman, in establishing an engineering factory at Aachen. Mr. Moser had been previously engaged by Mr. Robert Stephenson in connection with the station pumping machinery of the then London and Birmingham railway; and afterwards with the machinery of the Blackwall railway. In 1847 the partnership was dissolved, and Mr. Heppel returned to England, taking an appointment under Mr. Bidder on the North Staffordshire railway. While here he was associated with Mr. Phipps, M. Inst. C.E., in carrying out a series of experiments on the Stone canal, at the request of Mr. Bidder, in propelling canal boats by steam or other power instead of by horse power. After this Mr. Heppel was employed by Mr. Bidder about the early designs for the Victoria Docks, including the iron gates and caissons, then a novelty. On the conclusion of this engagement he remained in London until the year 1852, and during this time was occupied, among other works, in the investigation of the subject of the embankment and rectification of the River Tyne, for the late Mr. J. M. Rendel, Past-President Inst. C.E., resulting in an able report, equally characterised by sound theoretical reasoning and by practical recommendations, and which offers a good example of his ability in the application of mathematical principles to engineering questions. In 1852 Mr. Heppel accepted an appointment with Mr. Phipps, on the Western railway of Switzerland, a line in the Canton de Vaud, from Morges to Lausanne, and thence to Yverdun. Prior to its completion this work fell into litigation, and he then took charge of the Eastern railway of Switzerland for Mr. Hemans, Vice-President Inst. C.E., during which time he lived at Coire. Returning to England in the spring of 1856, he was engaged in reporting on lines of railway in Algiers and at Riga. About this time Mr. Heppel was consulted by Mr. Edwin Clark, M. Inst. C.E., on the practical working of the scheme for docking vessels for repairs in the Victoria (London) Docks by the hydraulic lift.[1] In designing these works it became an important matter so to arrange the assemblages of hydraulic presses as to include within them the variable position of the general centre of gravity occasioned by having to deal with vessels of different dimensions. This was accomplished by Mr. Heppel by the division of the presses into

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxvi., p. 292.

three separate groups, each of which lifted from its own centre of pressure, and acted similarly to lifting by three cords or chains, so that as long as the centre of gravity of the mass to be lifted lay within the triangle of which these formed the angles, perfect stability was ensured.

In the month of May, 1857, on the resignation of Mr. G. B. Bruce, M. Inst. C.E., Mr. Heppel was appointed Chief Engineer on the Madras Railway, and left London for Madras in July. He held this appointment for four years, and on his departure from Madras an order in council was passed commending his services. After his return to England these services were honourably mentioned by the late General Sim, in a report stating that the work designed and completed under his superintendence was not only cheap but excellent, and completed within the estimates. This was his last permanent engagement abroad, though he was continually occupied in reporting on engineering works both in the United Kingdom and on the Continent; an avocation for which his general knowledge as an engineer, his powers as a linguist, his capability of roughing it with small care for ease and comfort, and, it may be added, his gentlemanly and independent bearing, eminently fitted him.

In 1864 Mr. Heppel was appointed Consulting Engineer to the International Contract Company, and, in 1865, Engineer to the Peruvian railway. In 1866 he became Consulting Engineer to the Oude and Rohilkund railway, in which post his services, particularly in the improvement of the permanent way, were of an important character, and acknowledged as such by the company. He retained this appointment until his death, and some large bridges from his designs were then in course of construction.

Mr. Heppel joined the Institution as an Associate on the 20th of April, 1835, was elected a Graduate on January the 9th, 1838, and was transferred to the class of Member on the 11th of February, 1851. He contributed to the Proceedings Papers on the following subjects: "On the Relation between the Velocity and the Resistance encountered by Bodies moving through Fluids,"[1] for which he received a Telford Premium of Books; "On the relative proportions of the Top, Bottom, and Middle Webs of Iron Girders and Tubes,"[2] for which he was awarded a Telford Medal; "On a Method of Computing the Strains and Deflections of Continuous

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. v., p. 266.

[2] *Vide* Ibid., vol. xv., p. 155.

Beams under various conditions of Load;"[1] "On the Expansive Action of Steam;"[2] and "On the Closing of Reclamation Banks,"[3] for which he received a Telford Premium of Books. In 1869 he wrote a Paper "On the Theory of Continuous Beams," which was read before the Royal Society; and on this and other scientific subjects corresponded with the *élite* of the philosophical world, abroad as well as at home, by whom the originality and ability of his views were fully acknowledged.

Mr. Heppel invented several pieces of mechanism, the last being a water-meter, which was much commended. He took great interest in the plan of locomotion known as Fell's, and made some important suggestions for the improvement of the engines on the Mont Cenis railway. His opinion was sought by Mr. Bouch on the scheme for the railway bridge over the Forth, which he supported by able evidence before the Parliamentary Committee.

Mr. Heppel married, on the 21st of August, 1843, Elizabeth Mary, second daughter of the late Mr. Gosset, a surgeon of repute in Old Broad Street, by whom he has left a family of seven sons and three daughters. He was highly esteemed, both in private and professional life, by a large circle of friends, for his integrity and high principles. It may fairly be said that he combined within himself an unusually large amount of practical and theoretical information. Few men were more accessible; he always took great interest in scientific subjects, and was ever ready to afford the aid of his high mathematical powers to his less gifted friends. Finally, he was most averse to empiricism, all of his conclusions being founded upon the well-accepted and recognised truths of philosophy.

Early in 1871 Mr. Heppel was attacked by a severe cold, and soon afterwards showed symptoms of consumption. In January, 1872, he attended for the last time, and spoke at, a meeting of The Institution of Civil Engineers. He died on the 21st of March, 1872, in the 55th year of his age, and was buried in Kensal Green Cemetery.

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MR. DURAND KERSHAW was born on the 6th November, 1821. He was the eldest son of Mr. William Kershaw, partner in the house of Messrs. Marjoribanks, Bankers, of London. He was

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xix., p. 625.
[2] *Vide* Ibid., vol. vi., p. 316.
[3] *Vide* Ibid., vol. xxiii., p. 168.

educated by the Rev. Mr. Zilwood, of Compton Rectory, near Winchester; and was afterwards apprenticed to, and served his time with, Sir John Rennie, Past-President Inst. C.E.

He entered the service of Her Majesty as a member of the Ceylon Civil Service on the 30th of November, 1844; was appointed Assistant Civil Engineer on the 1st of October, 1846, and Assistant Commissioner of Roads on the 1st of January, 1851, when the two previously independent departments were combined under one head. In the autumn of 1853 he came to England on leave of absence for eighteen months, returning to Ceylon in February, 1855; but not being satisfied with his position and pay as a Government servant, at a time when many men were making large sums of money by coffee planting, he purchased a coffee estate, and left the Government service. He afterwards set up a manufactory at the town of Gampola, where he made and repaired machinery for coffee estates, &c., but neither coffee estate nor factory answered his expectations. He remained in Ceylon until his health, hitherto good, began to fail, and compelled him to leave the island in May, 1871. It was hoped that his native air would restore him to health, but he afforded another instance of the fatal "one year more" which has caused so many good and valuable men to die, either on their passage home from Indian climates, or soon after their return. A wish to carry out some pet scheme, to add another year's claim for pension, to save a little more money, have often prevailed over the warnings of failing health, and, it is to be feared, will continue to do so.

While in the service of Government Mr. Kershaw built a large number of bridges, some of which are called after him, and constructed many public buildings; among them may be mentioned the Queen's House, at Colombo, the official residence of the Governor. He also designed and carried out the construction of several of the more important private buildings which were erected before 1860.

Mr. Kershaw went to Ceylon at a time when a gradual change was being made from a strictly military rule to a civil one, when most of the appointments in the scientific branches of the service were held by military men, and were looked upon as a sort of regimental preserve. The value of the services of a clever civil engineer could not fail, under such circumstances, to be very great. He had to carry out large works with insufficient means, perhaps the most painful thing possible for a man in his position; and for these reasons he was sometimes obliged to use in

buildings a smaller quantity of material than he approved of. But his bridges are all solid and substantial, and so are all his other works for which sufficient means were allowed.

Mr. Durand Kershaw was quiet and unassuming in his manner, a kind friend, and a general favourite with all those who had the pleasure of his acquaintance. He was elected a Member of the Institution on the 7th of March, 1854, and died at Mount Row, Guernsey, on the 28th of August, 1871, leaving a wife and four children.

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Mr. ANDREW MURRAY was the second son of the late Andrew Murray, of Murrayshall, Perthshire. He was born in Edinburgh on the 19th of August, 1813, and was educated at the High School and Edinburgh Academy. He subsequently attended classes at the Edinburgh University under Professors Hope, Leslie, and others, and also studied mathematics under a private tutor. It was at first intended that he should go to Addiscombe, and, if possible, obtain a commission in the East India Company's Engineers; but the nomination from Sir Charles Forbes came just too late, he being then past the age for admission to that college. A commission in the Line was offered but declined, and he was thus again left to select a profession. His studies for Addiscombe, however, had developed a taste for mechanics, and civil engineering being then considered a rising profession, he turned his thoughts in that direction. He was perhaps somewhat confirmed in his selection by a trip made round the coast of Scotland with the late Mr. R. Stevenson, M. Inst. C.E., the Engineer of the Northern Lights Commissioners, of whom his father, as sheriff of Aberdeenshire, was one.

In 1832 he was apprenticed to Mr. (now Sir) William Fairbairn, M. Inst. C.E., and went to Manchester, where he remained for nearly five years. Mr. Fairbairn having determined upon the starting of a branch establishment at Millwall, a partnership for these works was agreed upon with Mr. Murray, on the understanding that Mr. Murray was to be the managing partner of that branch. He conducted these works for seven years, and during that time built several ships for the Russian, Prussian, and Danish governments, and also executed several contracts for the British Government.

The Millwall establishment, however, not answering expectations in the first instance, and the failure of the bank at Manchester rendering some reduction expedient, a dissolution of

partnership was agreed upon, and a vacancy occurring in the government service by the death of Mr. Ewart, at Woolwich, Mr. Murray was appointed Assistant Chief Engineer of that dockyard in 1843. Whilst at Woolwich he was ordered to make a report on the smitheries in all the Government dockyards, and also to arrange and lay out the plans, in conjunction with the late Sir William Denison, R.E., and Sir Henry James, R.E., for the steam factories to be erected at Portsmouth, both of which he did.

In May, 1846, he was appointed Chief Engineer of Portsmouth Dockyard, and it being at that time important, in consequence of foreign relations, to bring the factory there into operation as speedily as possible, his previous experience enabled him to accomplish this to the satisfaction of the Board of Admiralty. In 1853 he was appointed a member of a committee on the keeping of manufacturing accounts in Her Majesty's dockyards, and received the thanks of the Board for his services thereon; and in 1858 he was made a member of the Committee on Dockyard Economy, of which Admiral, now Sir Robert, Smart, was the chairman. During his service at Portsmouth many important changes were made at his suggestion, among which may be mentioned the system of keeping the accounts of the factory at Portsmouth in the manner of a private manufactory, which system was mentioned in an official report to the Treasury in the following favourable terms: "The success of the experiment reflects much credit on Mr. Murray, the Chief Engineer of the Portsmouth Factory." Another important change suggested by him was the admission of an entirely new class of men into the naval service under the name of "Engine-room artificers," by which the previously required number of engineer officers was reduced, and the means of executing small repairs on board was supplied. It was during his stay at Portsmouth, as Chief Engineer, that the first three-decker, the 'Duke of Wellington,' was fitted with the screw propeller in 1853; the first turret-ship, the 'Royal Sovereign,' was also fitted with her armour plating, without the erection of special machinery, and the revolving gear for her turrets was rendered both simple and effective under his supervision. The application of steam to ships' capstans, and of the twin screw machinery to ships' launches, was also the work of Mr. Murray, as well as the carrying out of the hydraulic propeller principle in Her Majesty's ship 'Waterwitch.' He was at Portsmouth, too, during the Crimean war, when the energies and abilities of all the dockyard officers were taxed to the uttermost.

In 1869, after nearly twenty-three years' service at that place, he was removed from Portsmouth, and made "Inspector of Factories and Consulting Engineer to the Admiralty at Whitehall;" but on the reconstruction of the Board in the following year, his retirement was decided upon, and he left the Government service in April, 1870.

Shortly before his death he made a trip to Canada as Director of a Company for utilizing the immense stores of titanic ore in that country. It was on his return that the symptoms of the fatal malady, which terminated his life, showed themselves, though no serious apprehensions were entertained till within a few weeks of his death, on the 13th of October, 1872. It may be mentioned that, on his return from Canada, he entered into an agreement with Mr. E. J. Reed, C.B., M. Inst. C.E., the late Chief Constructor of the Navy, for the survey of the engines of ships being built by that gentleman for foreign governments.

His time was too fully occupied throughout his life to allow of much literary work. He was, however, able to re-write the article on ship-building, in the later editions of the "Encyclopædia Britannica," an undertaking for which he was especially qualified, as he was present and rendered assistance in a long series of experiments on iron ship-building, conducted in Manchester during his apprenticeship in 1832; and he was the first to apply the results of these experiments, in conjunction with Mr. Fairbairn, at the Millwall establishment, on the Thames. He also wrote various professional papers on such subjects as the "Turbine Propeller," &c. Whilst in London in the earlier part of his life, he was a constant attendant at the Institution, and was elected an Associate on the 20th of March, 1838. In 1844, he contributed a Paper "On the Construction and Proper proportions of Boilers for the Generation of Steam," for which he was awarded a Telford Medal; and in the following year he served as Associate of Council. He was transferred to the class of Member on the 2nd of February, 1847, but his incessant occupation at Portsmouth prevented the continuance of these frequent visits, and it was not till he returned to London in 1869 that he was enabled to resume them with regularity. He was also a Member of the Society of Arts, and of the Institution of Naval Architects.

During his long stay at Portsmouth, and, in fact, throughout the whole of his life, he made many sincere friends, and it is not too much to say, that he was as much beloved for his genial and courteous manners as he was respected for his steady Christian principle, great professional knowledge, and sound judgment by

all with whom he was associated, whether in Her Majesty's Service or among private individuals. He gave the most ungrudging labour, sparing neither time nor thought when he could, either directly or indirectly, further the interests of the Service, his opinion and advice being always honestly and fearlessly given. That his abilities were highly valued, he had the satisfaction of feeling from the kind letters he received at the time of his retirement from many of the most distinguished officers of the Service, and also from the highly gratifying terms in which his name was mentioned by Mr. Corry, the late First Lord of the Admiralty, in a debate in the House of Commons, on April the 30th, 1870, on the reorganization of the Admiralty. As a mark of distinction, he was made a Civil Companion of the Order of the Bath in 1869, shortly after his removal to Whitehall.

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Mr. WILLIAM SCAMP was born on the 5th of June, 1801, at George Ham, near Barnstaple, where his father carried on the business of a maltster, occupying and farming his own land, as well as being the owner of vessels trading from that port. At the age of nine his father died; and the means of procuring an education befitting the ability then, though so early, developing itself was much interfered with. At twelve he had outstripped the knowledge of the local schoolmaster, particularly in geometry, astronomy, navigation, and land surveying, for each of which he showed a marked aptitude. The natural bent of his mind was, however, in the direction of engineering and architecture, and he applied himself with earnestness to the study of those subjects. His first work was the Assembly Rooms at Ilfracombe, which was carried out under his personal supervision, his design having been selected in competition. The qualities displayed by Mr. Scamp on that occasion procured him an appointment under Sir Jeffery Wyattville, then Mr. Wyatt, by whom, at the commencement of the restoration of Windsor Castle, he was selected to form one of the local establishment, from which most of the drawings for that large work emanated. Here his industry, perseverance, and energy, united with an iron frame and a good constitution, enabled him, during the thirteen years the works were in progress, not only to promote the interests of his chief, but likewise to lay a foundation upon which to build in after-years a name and reputation for himself. It was no uncommon thing for him, after working all

day in the office, to study the whole night, take a morning bath, have a pull on the Thames, and go back to the office again for another hard day's work.

On the approaching completion of Windsor Castle, he was appointed to the Works Department, Woolwich Dockyard, as assistant-engineer to Captain Denison, R.E., Assoc. Inst. C.E. (afterwards Lieut.-Gen. Sir William Denison, K.C.B.), under whom many important works were brought to a successful issue. While at Woolwich, Mr. Scamp introduced a vessel of novel design for agitating the mud in front of the dockyard at ebb tide. The mud was thus carried down the River Thames into deeper water, and many shoals were in this way removed at a trifling cost. During this employment the long-felt necessity for dock accommodation at Malta being again brought into prominence, by the urgent want of means for repairing the English fleet in the Mediterranean, Mr. Scamp, among others, applied himself to the solution of the problem; and in the year 1841 he was sent to Malta with a party under Captain Brandreth, Director of Engineering Works to the Admiralty, to report upon the possibility of carrying out the project. After carefully inspecting the harbour and vicinity, he submitted designs, which were finally approved; and he was appointed to carry them into effect. The foundation-stone of the dock was laid by Sir Patrick Stuart on the 28th of June, 1844, and the dock was opened on the 5th of September, 1848, when, for the first time, a British vessel of war was refitted at Malta for sea service. The execution of this work was attended with considerable engineering difficulties; but Mr. Scamp successfully overcame all obstacles, and so paved the way for making Malta, what it has eventually become, one of the chief naval stations in the world. He likewise remodelled the establishment, by designing and constructing a new bakery, coal stores, water tanks, officers' quarters, as well as many other improvements. While at Malta, the establishment at Gibraltar was placed under his control, and the New Mole and other works were completed, convict labour being, at his suggestion, extensively employed for the purpose. At this time, too, the Protestant church which was in course of erection at Malta, at the expense of the Dowager Queen Adelaide, showed such signs of settling down, part having actually given way, that immediate steps were necessary to avert a calamity, and to save the large expenditure already incurred. In this threatened crisis Mr. Scamp's aid was specially requested, and he advised a mode of dealing with the foundations which resulted in the perfect security of the building, admitting not only of its being finished as nearly as

possible according to the original plan, but also enabling a tower and spire (designed by him) to be added, which were not previously contemplated. This work was completed under his personal control, without the aid of contractors, and almost entirely by native labour. In acknowledging this service, which was gratuitous on his part, Her Majesty was pleased to signify her approval, not only by a gracious letter of thanks, but by presenting to him, at Windsor Castle, on his return to England, a costly silver candelabrum, with the following inscription:—"Presented by Her Majesty Queen Adelaide to W. Scamp, Esq., in grateful remembrance of his services in completing the Collegiate Church of St. Paul, at Malta. March 1st, 1845."

Mr. Scamp was recalled from Malta in 1845 to assume the post of Chief Assistant to the Director of Admiralty Works; and in April, 1852, he was appointed Deputy Director of Engineering and Architectural Works. His chief duties consisted in visiting and organising the Works' Department Staff, at the various naval establishments; and arranging for the efficient carrying out of the works designed at the central office at the Admiralty. To the excellent system of administration then initiated is mainly due the success which has attended the gigantic engineering works, since completed in those establishments, all over the empire.

The works with which Mr. Scamp has been connected as engineer on behalf of the Admiralty afford a memorial of a life of unceasing activity. The more important at Portsmouth, Devonport, Keyham, Chatham, Pembroke, and Woolwich, were designed to afford facilities for the construction and repair of the steam navy, then in embryo, and include a large dry dock at Keyham, two large dry docks at Devonport, with gates and apparatus, culvert wells, engine houses, &c., and several jetties, founded in deep water; and a new tunnel from Keyham to Devonport, connecting the two yards. Among other improvements introduced by him, the air-chamber and sluice arrangements, for working the largest caissons in closing dock entrances, are the most remarkable; not only from their simplicity and efficiency, but also for their economy. Among the seven caissons now in use at Keyham, that closing the deep entrance to the lock, upon which Mr. Scamp bestowed especial care and attention, stands conspicuous.

At the close of the Russian war of 1853–56, Mr. Scamp designed a hauling-up yard, for the preservation of the gun and mortar boats, numbering upwards of one hundred, as it was found they were subject to rapid deterioration in the basins, besides occupying much valuable space. The locality selected was Haslar Lake, near

Gosport; and in the course of two years the yard was ready for one hundred gun and mortar boats. The slip is in the form of a T, the stalk of the T running down into the creek. In this stalk a hauling-up cradle receives the boat out of the water and lands it on another cradle, which runs along the top of the T, and delivers the boat, by an endless screw, on either side, to the shed.

In the year 1860 Mr. Scamp projected the extension of the Grand Harbour at Malta, by the addition of about ninety acres to the water space of the harbour, and the construction of the surrounding quay wall. This was one of the largest engineering works carried out in modern times in the island. During its progress he visited Malta several times, and had the satisfaction of seeing it successfully completed.

The crowning feat of Mr. Scamp's life was the part which he took in designing the important works, now in progress, for the extension of Portsmouth and Chatham Dockyards. For five or six years before bringing forward the plans it was his practice to rise at 4 A.M. and work at them till the usual time for going to the office. Although Mr. Scamp has not lived to see the completion of these works, his name will be remembered in connection with them; and in the testimony which their existence bears to the skill of their designers his breadth of intellect and great genius will receive their full share of recognition.

Mr. Scamp was held in high estimation by his colleagues. In the year 1860 Colonel Greene, late Director of Admiralty Works, brought before the Board of Admiralty Mr. Scamp's claims for reward in these words:—

"And although the important services recently performed by Mr. Scamp would entitle him to every favour the Board could bestow, I will take wider ground, and base my recommendation on the services rendered by Mr. Scamp to the State during the fifteen years he has held the very arduous post of civil engineer to the Admiralty. During this interval no Admiralty work of any importance has been executed which has not received his most careful and constant attention. Many of the most considerable either originated with him or have been so entirely remodelled in accordance with his views as to become in fact his own. The present Admiralty establishments at Malta, Gibraltar, and Bermuda, are almost entirely projected by him. Deptford, Woolwich, Sheerness, Portsmouth, Devonport, and Pembroke, owe many of their best buildings to his professional talent. Keyham is almost entirely his own, from first to last. I feel I am not doing justice to Mr. Scamp in merely alluding to the establishments which owe so

much to him, but it would be tedious to enumerate in detail the specific works in each. I may indeed say, after an experience of thirty-five years, I have never met so efficient a public servant combining in himself, as he does, first-rate attainments as a civil engineer and architect, a thorough acquaintance with the minutiæ of every branch of the profession, complete knowledge of the difficult and intricate duties of surveyor and measurer, and an intimate acquaintance with the business of an accountant. All these unusual attainments he has, during the eleven years I have had the pleasure of working with him, brought to bear on his public duties at the Admiralty with an amount of energy, intelligence, and entire devotion to the service, seldom, if ever before, witnessed.

"I trust the Board will observe that I am not advocating the case of the Deputy Director of Works, but of Mr. Scamp, as a special and exceptional case. It is the work of the Crown to confer honorary distinction, as well as pecuniary rewards, for meritorious services; I beg very strongly to recommend Mr. Scamp for both. I know of no man better deserving their lordships' favour, and any distinction her gracious Majesty may confer."

Again, in August, 1867, Colonel (now Sir Andrew) Clarke, R.E., Assoc. Inst. C.E., when forwarding Mr. Scamp's papers to the secretary to the Admiralty, wrote:—

"No one knows better than you, sir, the important and valuable service this gentleman has, during a professional career of half a century, rendered the sovereign and the country, nor could language of mine in recapitulating those services place them before you more clearly than that used by the late Director of Works in his Minutes of 9th December, 1858, and 20th November, 1860, attached to this letter, and in which I fully concur."

Towards the close of the year 1867 Mr. Scamp retired from the public service. Having taken this step, the Board recommended the Treasury to allow him full pay; and in the letter accompanying the announcement that this had been conceded, they acknowledged in handsome terms the service he had rendered to the State.

After Mr. Scamp's retirement, his health, which had previously begun to show signs of giving way, completely failed; to the last, however, he employed his mind upon questions of large engineering interest; and, before his death, he had prepared a report and elaborate plans, for the reclamation of land in Morecamb Bay, and for the improvement of Lancaster Harbour as a mercantile port, which he believed might be made to rival Liverpool, if not, by reason of its natural advantages, even to surpass it.

On the 13th of January, 1872, after a week's illness, he died from congestion of the lungs.

He was upright, straightforward, and outspoken; no courtier, nor subtle diplomatist, seeking his own advancement. His motto was "duty." He acted up to it himself, he expected others to do the same. He was devotedly attached to his wife and children; no self-sacrifice seemed too great for their good; and it was only when their health demanded it, that he absented himself from public duties. The loss of both his sons, each having attained the age of manhood, was a severe blow to him; but his unswerving sense of duty enabled him to work on steadfastly and manfully in the face of these afflictions. He died at the age of seventy, after a life faithfully and uprightly devoted to the public service.

Mr. Scamp was elected a Member of the Institution on the 6th of March, 1849, and for many years he attended the evening meetings; but latterly professional duties seldom permitted his doing so.

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Mr. RICHARD SMALLMAN was born in Dublin in the year 1816. His family removed immediately afterwards to London, where he passed the first seven years of his life; but at the end of that period they returned to Ireland, and Mr. Smallman received the rudiments of his education in his native city. At the age of sixteen he was articled to Mr. Rowland Gray, at that time Engineer to a northern Irish county, where he learned the principles and practice of surveying; and was for some time employed on the Ordnance Survey of Ireland. A few years later, Mr. Smallman became an assistant of Mr. C. B. Vignoles, Past-President Inst. C.E., when he was engaged on the Dublin and Kingstown railway, and on the survey of various Irish lines of railway. He subsequently was engaged, under Mr. Vignoles, in the surveys of the Manchester and Sheffield, the Midland Counties, and several other lines of railway in the Northern and Midland districts. In the dull years for the profession, 1839 to 1842, Mr. Smallman, like many other engineers, was thrown out of employment, and suffered some hardships and privations. But his energy, talent, and unflagging industry overcame these difficulties; and when, about the year 1844, railway business revived, he soon found employment on the survey of the new line of railway from Lancaster to Carlisle, where he secured the position of Resident Engineer during construction. He was afterwards engaged for a short period in the Parliamentary Survey of the line from Carlisle to Glasgow and

Edinburgh, at that time called the Caledonian railway. In the year 1847, Mr. Smallman was appointed Resident Engineer on the Little North Western railway, a line between Settle and Leeds, with its branches. Here he remained for ten years, as Engineer during construction, and afterwards as Superintendent of Permanent Way and Works, and also of Locomotives. At the same time he had the supervision of a branch line to Poulton-le-Sands, and the construction of extensive docks at that seaport, of which Messrs. Coulthard and Allen were the contractors, they being also contractors of a considerable portion of the Little North Western railway, on which were some large masonry works, including two viaducts over the Crook of Lune at Caton.

In the year 1857 Mr. Smallman was offered, and accepted, the appointment of principal Resident Engineer of the Bahia and San Francisco railway in the Brazils, Mr. Vignoles being the Consulting Engineer, and Messrs. John Watson and Co. the contractors. He sailed for that country shortly after, and previous to his departure was presented with a service of plate, the gift of numbers of his attached friends, both private and professional, in Lancaster and its neighbourhood, where he had resided for a number of years.

Mr. Smallman did not remain long in the Brazils. Shortly after his arrival at Bahia, he was seized with severe and dangerous illness, so much so as to necessitate his return to England in a few months. After his return his health rapidly improved, and he found an appointment on a line then about to be commenced, from Sedburgh-by-Orton to the Lancaster and Carlisle railway near Shap. Subsequently, Mr. Smallman became principal managing agent to Messrs. John Watson and Co., who had by this time achieved a prominent position as contractors, and who had, besides their contract in the Brazils, numerous other contracts in England, Ireland, and Wales, the principal being the Mid-Wales railway, and the Newry and Armagh railway, on which were some extensive works. In this capacity he continued until the year 1866, which proved so disastrous to the commercial community generally. Mr. Smallman was afterwards occupied in winding up the affairs of railway companies in liquidation to within a short time of his death, which occurred on the 27th of March, 1872, in his 56th year.

During a long course of professional practice Mr. Smallman proved himself an able Engineer: he was an accomplished draftsman, and a thorough office man of business generally; and not less so in an out-of-door capacity, being a quick and able surveyor and leveller; and, later in life, when called upon to design and

superintend the construction of large and extensive works on the several lines of railway, he acquitted himself with the greatest credit. He had a singular and happy knack of managing contractors and workpeople--a far-seeing eye for economy in construction, and—whilst constantly studying the best interests of the railway companies by whom he was employed—he was no less a friend to the contractors, treating them with justice, as evinced by his decision in several arbitration cases. He was ready at all times to give his friends the benefit of his talents and experience; and many members of the profession are much indebted to him for advice and assistance in their younger days.

Mr. Smallman was elected a Member of the Institution on the 4th of March, 1862.

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Mr. HENRY JOHNSTON WYLIE was born in Edinburgh on the 5th of July, 1822. His earlier education was obtained at the Academy of his native city, and his studies were completed at the Glasgow University. The manifestation, at an early age, of a taste for mechanical and scientific pursuits, led to his being apprenticed to Mr. George Marten, of Glasgow; and he subsequently became attached to the staff of the late Mr. Gunn, M. Inst. C.E. During this engagement Mr. Wylie formed a friendship with his fellow-assistant, Mr. James Peddie, and the result was a partnership between them, and the joint execution of a number of important public works. Amongst these were the Selkirk and Galashiels railway, opened early in 1856, the Bridport railway, completed in 1857, the Kirkcudbright railway, opened in 1864, and, in connection with Mr. Jopp, M. Inst. C.E., the Berwickshire railway, opened in 1863. Mr. Wylie also contributed materially in obtaining the Act for the Galashiels and Peebles railway, in the session 1859-60, and he had a considerable practice in the resolution of questions under reference from the Judges of the Court of Session. In 1867, in conjunction with his partner, he commenced the Kirkcudbright swing-bridge, an important work over the navigable portion of the River Dee; and this was completed in the following year.

At the close of 1868, Mr. Wylie, having been selected for an appointment in connection with the Home Department of the Indian State railways, left his native city and took up his residence in London; but a controversy arising as to the preferable gauge to be adopted, which prevented active operations, he accepted an

appointment to visit and report upon the Tasmanian railway, of which he was also the Consulting Engineer. The labour and exertion experienced in this expedition, aggravating a deep-seated pulmonary complaint, overtaxed his strength; and his death took place at his sister's house at Melbourne, Australia, on the 3rd of November, 1871, in the 50th year of his age.

By sterling integrity and honourable conduct as an Engineer, by a genial and kindly disposition in private life, and by an unvarying consideration for all who came in contact with him, Mr. Wylie secured and retained the good opinion of an extensive circle of friends and acquaintances, both for his professional abilities as well as for his worth as a friend.

Mr. Wylie was elected a Member of the Institution on the 2nd of February, 1869.

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Mr. JAMES BAGNALL was born at West Bromwich, in the county of Stafford, on the 31st of December, 1804. He was the sixth son of Mr. John Bagnall, coal and ironmaster, of Tipton and West Bromwich, by his second wife. His father admitted five of his sons into copartnership with him, of which James was the youngest; and when he died he was the only member left in the firm of "John Bagnall and Sons" thus constituted, having carried on the extensive ironworks and collieries single handed after the death of his brother William,[1] in 1863. He took great interest in the moral and spiritual welfare of his workpeople. Schools were built by the firm at Gold's Hill for the benefit of their children, which were licenced for Divine worship, and a chaplain was appointed in June, 1853. These institutions he continued to support until his death; and while others similarly situated, when they had acquired a fortune, left the smoky district and retired into the country, he continued to reside among his own people to the last. He was for some years an active county magistrate, having been appointed a justice of the peace in October, 1845. He was afterwards made a deputy-lieutenant for the county of Stafford. He died at Meyrick House, West Bromwich, on the 12th of January, 1872, leaving no issue, and was followed to the grave, at All Saints' Church in the same parish, by thousands of his work-people and his poorer neighbours, who thus testified their affectionate regard for him.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxiv., p. 510.

A funeral sermon was preached at St. James's Church, adjoining his residence at Hill Top, by the chaplain, who said: "I would recall to your memory that not only was the structure in which we are now assembled erected mainly by his unwearied exertions, but the baptistry, the beautiful organ, and the pretty east window, owe their existence wholly to him; and as long as these walls stand, they will be a witness to James Bagnall having been a benefactor to Hill Top—to say nothing of the National Schools, towards the building of which he was so liberal a contributor; even as the school-church will bear testimony to the same truth at Gold's Hill. And, as to his charity, I remember, twenty years ago, being present at an annual treat he was wont to give to the children of the church and to the members of the congregation—when, with beaming countenance, he was the leader in all the children's pastimes, and identified his happiness with theirs, affording pleasure to many hundreds of people. And I recollect, also, on two or three occasions, being present at what was at the time an annual Christmas sight, viz., the giving away in great profusion blankets, sheets, shirts, flannels, and other things to persons represented to him as being deserving of his benevolence; and at that time his eye would sparkle with pleasure, his whole countenance would be beaming with benignity; and, as the recipients of his bounty, one and all, thanked him, I have heard him say, 'Don't thank me, my friends, but thank God for what I give you—He gave it to me. My father was at one time a man of the people, and see how greatly the Lord has blessed him and his children!' I was so struck by what he said—it was so truly noble, so full of deep religious sentiment, that I have never forgotten it, but have often reminded my old friend of the fact, and said, that if ever I was called upon to preach his funeral sermon, I would introduce that incident into it."

Mr. Bagnall was elected an Associate of the Institution of Civil Engineers on the 16th of February, 1841.

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Mr. EDWARD BANFIELD, second son of Mr. John Banfield, of Ilfracombe, and grandson of the late Mr. Richard Trevithick, was born the 9th of February, 1837. Being delicate, he was not sent to school till 1849, having up to that time received instruction from a private tutor. Subsequently he entered the factory of Messrs. Harvey and Co. at Hayle, where he remained till 1855, when he went to Paris, and placed himself under M. Test—who

prepared young men for the École Centrale—and studied mathematics till December, 1857.

In March, 1858, he left England to join his uncle, Mr. Frederick Henry Trevithick, at Montreal, and was for three years employed in the locomotive department of the Grand Trunk railway. In May, 1861, he was appointed manager of Mr. Foley's Ramsey lead mine, at Carleton, Canada West; but the operations not proving successful, he only held the appointment for about a year. While in Canada he assisted Mr. Clarke in illuminating the Falls of Niagara, on the occasion of the visit of the Prince of Wales, who was so much struck with the magnificent effect, that His Royal Highness requested it might be repeated on the following night. In January, 1862, he returned to England, and was for a short time in Mr. West's factory, at St. Blazey, Cornwall. In June, 1862, he became the manager of the Homburg and Frankfort line, where he remained till December, 1864. In this position he occasionally had to contend with vexations arising from the management of a staff jealous perhaps of subordination to one of a different nationality to themselves; but the good-nature, tact, and firmness, which afterwards became his chief characteristics, sufficed to carry him through all difficulties, and he left Germany with the good wishes of a large circle of friends.

On the 17th of January, 1865, he married his cousin Jane, eldest daughter of Mr. John Harvey Trevithick, of Hayle, and soon after proceeded to South America, to undertake the management of the Buenos Ayres Great Southern railway, then newly opened. As manager of this line he became known and appreciated all over the province, and the success of the railway was on several occasions stated by the London directors to be entirely owing to his exertions. Among other improvements he introduced a system of carrying wool—a staple product of the country, and the source of large revenue to the railway—in the country bullock carts without unlading, by means of low trucks. This avoided the necessity of using bags, and greatly facilitated the conduct of the traffic. In November, 1867, he was obliged to come home in consequence of ill-health, but returned in the following May, and from that time until May, 1872, devoted the whole of his energies to the working of the railway. He carried out the Salado Extension under somewhat difficult circumstances, the Government of Buenos Ayres wishing to make an independent line of their own, and thwarting him in every way. But he overcame their opposition, and the Salado Extension is a notable example of cheap and efficient railway construction, it having been

completed as a first-class line, and laid with steel rails on wrought-iron sleepers, for £4,500 a mile, exclusive of rolling-stock. He also superintended, with a like result, the construction of the Azul and Tandil Extension.

In November, 1871, Mr. Banfield, owing to a second attack of severe and weakening illness, and acting under medical advice, was compelled to resign his appointment and return to England. Unfortunately it was too late; for, arriving in England on the 14th of June, he lingered a few weeks, and died on the 6th of July, 1872, at the house of his uncle, Mr. F. H. Trevithick, in London, leaving a widow and three daughters, the eldest under six years of age. The Directors of the Buenos Ayres Great Southern Company, in their Report, dated the 17th of May, 1872, put on record, that "It is with deep regret that the Board have to announce the resignation of Mr. Edward Banfield, who has been General Manager of the Railway in Buenos Ayres since the commencement of the Company, and whose valuable services as an administrator, in organising and developing the traffic of the railway, entitle him to the best thanks and special consideration of the Shareholders." This resulted in his being presented with a sum of £2,000, as a recognition of his labours in connection with the Salado and the Azul and Tandil Extensions; but an even more gratifying testimonial was the receipt of a handsome service of plate, duly inscribed, and accompanied by an illuminated address signed by twenty-two of his fellow associates in the service of the Company.

Mr. Banfield was elected an Associate of the Institution on the 23rd of May, 1871, but his residence abroad prevented his taking an active part in its proceedings.

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Mr. JOSEPH BAXENDALE was the eldest son of a surgeon in Lancaster, where he was born in September, 1785. At an early age he joined Messrs. Swainson, of Preston, calico printers; but in 1817, having some time before married a daughter of Mr. John Birley, of Blackburn, he entered the concern of Pickford and Co., in which he soon became the leading partner. He managed it with remarkable skill and success, and he retained this position to the time of his death.

As the largest carrier probably in England, Mr. Baxendale was naturally brought into communication with the leading canal and railway engineers, by most, if not by all, of whom he was more or less intimately known. With George and Robert Stephenson he had

a constant intercourse of the most friendly character. He was elected an Associate of the Institution on the 8th of February, 1839; and having been Chairman of the South Eastern Railway Company during the construction of the most important works, his acquaintance with the late Sir W. Cubitt, Past-President Inst. C.E., ripened into a friendship only terminated by death. It was during this period of his life that Mr. Baxendale was most intimately connected with civil engineering. He travelled constantly with Sir W. Cubitt to inspect the work, and was present at the great blast of the Shakspeare Cliff. He purchased the harbour of Folkestone for the South Eastern Railway Company, and took a leading part in the improvements by which it was converted into a port for continental traffic. Mr. Baxendale was also for many years, and up to his death, a Director of the East Indian railway, in which position he came into communication with the late Mr. Rendel, Past-President Inst. C.E., for whom he had a great regard, and whose death was a severe blow to him.

Though no engineer himself, Mr. Baxendale fully appreciated the qualities which distinguished the leaders of the profession, and, so far as his scanty leisure would permit, cultivated their acquaintance. To the end of his life he took much interest in the Smeatonian Society, of which he was one of four honorary members, Dr. Roget and William Cotton being among them.

Mr. Baxendale retired from the chair of the South Eastern Railway Company at the close of 1844, and not long after from the active management of his own concern, the affairs of which, however, he superintended till a recent period.

He resided chiefly at Woodside, on the Old North Road, on the borders of Middlesex and Herts, where he had made extensive grounds and gardens; and he died there on the 24th of March, 1872.

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Mr. EDWARD LADD BETTS was born at Bucklands, near Dover, on the 5th of June, 1815. He was the eldest son of Mr. William Betts, of Sandown, Kent. At an early age he was apprenticed to a builder named Richardson, in Lincoln, and showed great aptitude for mechanical pursuits, having constructed a small working model of a steam-engine. The first contract on which he was practically engaged, under the superintendence of his father, who was for many years associated with the eminent contractor, Mr. M'Intosh, was the erection of the Black Rock Lighthouse, near Beaumaris, North Wales. On the completion of this work, when only eighteen years old, he superintended the con-

struction of the Dutton Viaduct, on the Liverpool and Birmingham railway, at first under Mr. George Stephenson, and afterwards under his successor, the late Mr. Joseph Locke, M.P., Past-President Inst. C.E. This was a work of considerable magnitude, executed at a time when the facilities in use at the present day for carrying out such an undertaking were unknown. From this period to the close of his life Mr. Betts was continually engaged in various railway works, many of which were of a difficult character, requiring organization of no ordinary nature, but for which his talents were peculiarly adapted. The Midland railway from Rugby to Leicester, the South-Eastern from Reigate to Dover, the line from Paddock Wood to Maidstone, and the North Wales mineral railway from Chester to Wrexham, followed in rapid succession. In the year 1845 Mr. Betts entered into a contract for the first section of the Chester and Holyhead, and the Chester and Mold railways. These works, together with the line through the island of Anglesea to Holyhead, were carried out under the direction of the late Mr. A. M. Ross, who was associated with the late Mr. Robert Stephenson, M.P., Past-President Inst. C.E. On the completion of the last-named contract Mr. Betts entered into partnership with Sir S. Morton Peto, Bart., and constructed the Great Northern loop line from Peterborough, through Boston, Lincoln, and Gainsborough, to Doncaster; the East Lincolnshire railway from Boston to Louth; the Oxford and Birmingham; the Oxford, Worcester, and Wolverhampton; the Great Southern of Buenos Ayres; and the Dunaburg and Witepsk railway, in Russia; also the line from Algiers to Bledah, for the French Government, and many smaller works, including the Netherlands land drainage. It was at the suggestion of Sir S. Morton Peto, during the war in the Crimea, that the English Government was induced to give an order for the construction of a railway from Balaclava to the camp, for the purpose of conveying material and ammunition for the siege of Sebastopol. Mr. Betts undertook the entire organization of this important enterprise, and with such energy, that in a few weeks from its commencement the line was in working order. Many large and important works were executed by Messrs. Peto and Betts in connection with the late Mr. Brassey. The Grand Trunk railway of Canada (including the Victoria Tubular Bridge across the River St. Lawrence at Montreal) may be mentioned as one of great magnitude. The Jutland and North and South Schleswig railways, in Denmark; the Lyons and Avignon, in France; the Tilbury and Southend; the Hereford, Ross, and Gloucester; the South London and Crystal Palace railways; the Victoria (London) Docks; the Thames

Graving Docks; and many other works, were successfully carried to completion, principally under Mr. Betts' personal supervision. The firm of Peto and Betts, in partnership with Mr. Crampton, constructed the whole of the London, Chatham, and Dover railway, including two bridges across the Thames. Those only who are practically acquainted with the execution of large works, requiring constant and unremitting attention, can in any measure appreciate the amount of energy and mental labour expended by Mr. Betts on these various enterprises.

Mr. Betts was elected an Associate of the Institution of Civil Engineers the 26th of June, 1849. In 1851 and 1852 he filled the office of Chairman of the Eastern Counties Railway Company. This was a period of great anxiety to him, and a strike of the engine-drivers employed on the line added to the difficulties of the management. His vigour and determination were never more forcibly shown than on this occasion, when he not only completely suppressed the movement, and prevented it extending to other railways (as it was feared it might), but at the same time carried on the traffic with little interruption. An accident, which affected his eyesight, compelled him to resign the position he had held with so much benefit to the company. Mr. Betts married, in 1843, the youngest daughter of Mr. William Peto, of Cookham, Berks. He was a magistrate and deputy-lieutenant for the county of Kent, and in 1858 served as high sheriff for that county. In the year 1865 he contested the representation of Maidstone in the Conservative interest.

This brief sketch of Mr. Betts' life would be incomplete without some allusion to his private and domestic worth—his untiring application to all the duties of life, and indomitable energy in fulfilling them—his stern rectitude in all dealings with his fellow-men, added to his general benevolence, nobleness of character, and the warmth and generosity of his friendships. How often he held out a helping hand to those in difficulties, or started others in life who owe their subsequent success to him, many might attest, and some have gratefully acknowledged. Mr. Betts was gifted with a clear judgment and a vigorous mind that grasped at once the main points of a question, and quickly decided on its merits. This almost intuitive perception of character enabled him promptly to estimate men's worth and their capacity for any given work. That he was not often deceived in this respect is proved by the many life-long friendships he formed, and by the number of years his agents and employés continued to serve him with attachment and fidelity.

Declining health and the strong recommendations of his physicians induced him in the autumn of 1871 to go to Egypt, in the hope that a winter in that climate would restore his strength. But it was not to be; years of unceasing labour had done their work but too surely; and on the morning of Sunday, January 21st, 1872, he peacefully passed away, at the age of 56, at Assouan, Upper Egypt. His remains were brought to England, and were interred at Aylesford, Kent, in which parish he had for many years resided.

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Mr. CHARLES WILLIAM DIXON, the second son of Mr. Benjamin Dixon of Pledwick, near Wakefield, was educated partly at the West Riding Proprietary School, in his native town, and partly at Scarborough, under the tutorship of the Rev. John Oates, the present head master of St. Peter's College, Guernsey.

Having early showed a predilection for mechanics, he was articled in the year 1862 to Mr. James Kitson, M. Inst. C.E., of the firm of Kitson, Thompson, and Hewetson, Leeds. Having studied practical detail in the workshops and fitting-sheds, he, on the expiration of his articles, filled several situations for short periods, and was then for two years a partner in the firm of Kirk and Co., of the New Yard Rolling Mills, Workington. Subsequently his attention was turned more to the theory of the profession, and the mechanical ingenuity which marked his short career was displayed in several suggestions for improvements which he believed would be found of practical utility. In the year 1867 he introduced an "Invention for improvements in mounting Wheels on Axles, the same being specially applicable to Railway Wheels;" and about the same date invented an "Improved Slide Valve."

He was elected an Associate of the Institution of Civil Engineers on the 4th of February, 1868. After some years of failing health, he died at Wiesbaden, in Germany, on the 27th of December, 1871, aged thirty-one years.

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Mr. THOMAS DUNN was born on the 11th of July, 1813, at Leftwich Green, which was then an open common near Northwich, and was sent to school at Whitley, Cheshire, boarding with his grandfather, Mr. Thomas Burgess, a small farmer, who lived on the edge of Bartington Heath. At fifteen years of age he went to Northwich, but could not settle to anything. With one master he wasted the paint by operating with it on the boys; with another,

who was a joiner, he cut the tenons off the rails and styles set out for re-pewing the Methodist chapel. Then he tried his hand at sail-making, and again as a stone-mason, and in the intervals he was with his father. He was afterwards turned over to assist his mother as a grocer and general dealer, but treated her customers so that she had nothing but complaints, and she strongly advised him to try again at some mechanical trade. He therefore turned out one night to see if he could find anything in the dark, as all he had tried in daylight had been ineffectual. He went through the town of Northwich, and out by Baron's Quay, where he saw a strong light, and heard a great noise at the old foundry, and obtained a first-rate view of the casting process and general uproar of a foundry. He then and there determined, if he could only get a situation in this line, that nothing should induce him to leave it. He got it, and acted on the principle of making himself as useful as possible. He ran and fetched anything for the men, waited on the apprentices older than himself, struck for the smiths, rammed up sand for the moulders, slurred up for the loam men, and waited on everybody, so that he was considered the handiest lad on the works. Whether belonging to their branch or not, all wanted him —millwrights, fitters, turners, and erectors. About that time a dispute arose amongst the partners, which threw him out of position, and he engaged to go to Middlewich, a small salt town 6 miles south of Northwich. He remained there three months, and was sent to erect an engine and bark-mill at Warrington, 12 miles east of Northwich. He was next engaged to go back to his old foundry, at a much improved salary; but, finding no scope for improvement, he went to Manchester. He was articled to Mr. Ormerod, of the George Foundry, where he began to make designs of machinery, to perfect himself in which he embraced the facilities offered by the Manchester Mechanics' Institution, and, having done so, started on his travels through different parts of the country, then on to Ireland, and back again to Lancashire, where he obtained a situation at Messrs. Jones and Potts' works, Warrington Junction, on the Manchester and Liverpool railway. From there he went to the St. Helens and Runcorn Gap Railway locomotive works, to superintend the construction of some tipping machines at Widnes dock. Being now twenty-two years of age, his father built a small foundry for him at Leftwich, where he had a partner, to whom he ultimately sold his share of the business, and proceeded to London, at the time railways were coming into vogue. After looking about for some time, Mr. Dunn met with Mr. Cardus, an old contractor of his acquaintance from Lancashire, who got him engaged at once as

a foreman. He was now twenty-three years of age, and had three hundred men under him. He found that the discipline he had willingly undertaken at the Baron's Quay Foundry was not thrown away; and he secured the friendship of the late Mr. J. H. Beattie, M. Inst. C.E. After finishing the works on which he was engaged in London, Mr. Dunn went to Holland for a short time, but returned on account of his health. In the year 1838 he took the management of the St. George's Foundry, where he was promised a small share in the profits; but, being disappointed, he started the Windsor Bridge Iron Works at Pendleton, near Manchester, in 1847; but they did not prove successful. Between March, 1845, and November, 1871, Mr. Dunn took out twenty-three patents, principally for improvements in machinery. One of them, dated the 18th of March, 1862, for "Improvements in the construction of bridges, roofs, houses, and other structures," cost £662 10*s.* for printing and paper, and the price of the specification was £2 13*s.* per copy. He was a Member of the Institution of Mechanical Engineers, of the Institution of Naval Architects, and of the North of England Institute of Mining and Mechanical Engineers; and was elected an Associate of the Institution of Civil Engineers on the 4th of April, 1854.

He died on the 15th of December, 1871, and was buried on the 20th of the same month in Davenham churchyard, Cheshire.

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Mr. JOHN SAMUEL ENYS, who was born on the 21st of September, 1796, was lineally descended from the ancient family of Enys, of Enys, where his ancestors had been located even from the time of the Plantagenets. In the first parliament of Charles II. Samuel Enys, Esq., represented Penryn, and the name of the family appears on every page of the list of county sheriffs.

Mr. J. S. Enys was educated at Winchester, matriculated at Exeter College, Oxford, and took an honorary third in classics. He succeeded to the family estates about half a century ago, on the decease of his great-uncle, Francis Enys, Esq., and he first directed his attention to Scotch farming on the land which he retained in his own hands.

Energies such as he possessed, combined with an insatiable desire for the acquisition of knowledge, could not long be confined to farming. He became an active magistrate, and in the public business of the county his high integrity and sound opinion soon gained for him the confidence of all; he was thus enabled to

bring forward and carry many useful improvements in the roads, bridges, and general communications of the county.

He next turned his attention to the improvements in the steam-engines used for pumping at the Cornish mines, which had been introduced by Trevithick and others, whose merit he desired to have recognised; and upon this and kindred subjects he wrote several interesting and useful papers which have been printed in the "Minutes of Proceedings of the Institution of Civil Engineers," the "Transactions of the Royal Cornwall Polytechnic Society," the "Reports of the British Association," &c. A list of the majority of them is appended to this Memoir.

Forming an acquaintance with the late Sir Henry de la Bèche, then superintending the Government geological survey of Cornwall, sufficed to direct his attention to geology and mineralogy, and especially to that of his own immediate district, and in this he found great aid in the facility of pencil, which he had assiduously cultivated, originally in the study of architecture, in which he attained considerable proficiency. Of this he found the benefit when, in after years, he visited Italy with his family, and beguiled the weariness of forced repose, which, during the first attacks of his illness, would otherwise have been very irksome to his active spirit. The interest he took in improving the form and stability of fishing-boats, and, eventually, of larger craft, must not be omitted; and he worked out by calculation, drawings, and models, some interesting problems in ship-building. He married Miss Catherine, the eldest daughter of the late Davies Giddy Gilbert, of Eastbourne, then President of the Royal Society; and thus becoming acquainted with all the best scientific men of the day, he entered with avidity into the numerous improvements of the period, and had free scope for his energy and intelligence. Up to within a few years of his death he was a constant attendant at the meetings of the British Association, as of the learned and scientific societies of the metropolis of his own country, and his decease, which occurred on the 29th of May, 1872, is as much regretted among the large circle of friends he had made as in his own family circle, where his uprightness, probity, high feeling, and affection for all around him were justly estimated. He was a worthy model English country gentleman.

He joined The Institution of Civil Engineers as an Associate March the 12th, 1839, and was a very frequent attendant at the Meetings, writing Papers, and taking an active part in the Discussions.

Papers published by Mr. J. S. Enys in the Transactions of Learned and Scientific Societies, &c.:—

"Some Remarks on the Granite found near Penryn, and on the Mode of Working it." (London Phil. Mag. May, 1833, p. 321.)

"Tables relative to the Properties and Practical Application of Steam." (Trans. Roy. Cornwall Poly. Soc. 1835, p. 44.)

"Observations on the Application of Expansive Steam." (Trans. Roy. Cornwall Poly. Soc. 1836, p. 70.)

"On the Performance of Steam Engines in Corwall." (Report Brit. Assoc. 1836, p. 130.)

"Observations on Duty and Horse Power." (Trans. Roy. Cornwall Poly. Soc. 1837, p. 70.)

"Observations on Expansion Diagrams and on the Duty of Scoop Wheels and Pumps in Draining Fens." (Trans. Roy. Cornwall Poly. Soc. 1838, p. 154.)

"The Application to Government for a Depository for Mining Records." (Report Brit. Assoc. 1839, p. xxiii.)

"Remarks on the Duty of the Steam Engines employed in the Mines of Cornwall at different Periods." (Transactions of The Institution of Civil Engineers, vol. iii., p. 449.)

"Remarks on the Connection which exists between Improvements in Pit Works and the Duty of Steam Engines in Cornwall." (Report Brit. Assoc. 1841, p. 103.)

"Report of a Committee appointed at the Tenth Meeting of the Association on the Construction of a Constant Indicator for Steam Engines." (Report Brit. Assoc. 1841, p. 307.)

"Remarks on Floating Light Vessels." (Trans. Roy. Cornwall Poly. Soc. 1842, p. 71.)

"Remarks on Ships' Fastenings and Steamboats." (Trans. Roy. Cornwall Poly. Soc. 1842, p. 107.)

"Report of the Royal Cornwall Polytechnic Society Premiums offered by J. S. Enys." (Trans. Roy. Cornwall Poly. Soc. 1843.)

"Plan for Floating Light Vessels and Buoys." (Trans. Roy Cornwall Poly. Soc. 1851, p. 35.)

"On the Application of the Displacement Curves of Fish to the Construction of Boats." (Trans. Roy. Cornwall Poly. Soc. 1854, p. 41.)

"Photographs of Quarries near Penryn, showing the Structure of the Granite." (Report Brit. Assoc. 1858, p. 80.)

"Remarks on the Intensity and Quantity of the Junction Changes of Sussex and Cornwall, considered as Mining Districts." 1863.

"On Specimens of Hornblende and Serpentine from the Junction at Porthalla." (Trans. Roy. Cornwall Poly. Soc. 1863, p. 43.)
"On the Probable Course of the Tyrian or Carthaginian Ships to Cornwall." (Trans. Roy. Cornwall Poly. Soc. 1866, p. 68.)

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Mr. CHARLES AARON HASLETT was born at Hallowell, in the State of Maine, in the year 1822. At an early age he manifested precocious talents in mathematics. He attended a High School, and was trained as a teacher, more especially with reference to that branch of science. His health, however, would not permit him to follow that comparatively sedentary calling, and he therefore commenced a course of studies in civil engineering, under Mr. Mason of Cambridge, Massachusetts. This was about the year 1848; and he soon after became eminent as a railway surveyor, and compiled "The Engineer's Pocket Field Book," which became at once the reference and the companion of railway Engineers in the United States and Canada. It gives a compendium of the American system of laying out curves on railways, and embraces numerous tables and original formulæ. It is believed that Mr. Haslett was the first to introduce the system of calculation by Versed Sines, by which many problems of field work are abbreviated. After the publication of this book, Mr. Haslett's services as a 'Locating Engineer' were eagerly sought after by railway companies.

The principal railways in which he was engaged were the European and North American and the St. Andrew's, in New Brunswick, where he served under Mr. A. L. Light, M. Inst. C.E.; the Intercolonial railway of Canada, under Mr. H. G. C. Ketchum, Assoc. Inst. C.E.; the San Paulo railway of Brazil, where he was employed in the construction of the celebrated inclines, and of the Mugi Viaduct, designed by Mr. Brunlees, M. Inst. C.E.; the Virginian Central, the Union Pacific, the Western Pacific, and many smaller railways of the United States; and finally, Mr. Haslett was chief of the surveying staff on the Southern Pacific railway of California, where he died in June, 1872. He had just completed the survey of the last-named railway, and was returning to San Francisco, where he had left his family, when he was suddenly seized with bilious colic, accompanied by violent cramps. All the remedies that could be procured by the surveying party were immediately applied and administered, but without avail. No physician was within reach he was in the midst of a sandy desert,

where the intense heat and the alkaline nature of the waters seemed only to increase his sufferings and accelerated his death. His body could not be brought to San Francisco, owing to the distance it would have to be carried over the sand and through the heat. Consequently, definite measurements were taken by the surveying party to determine the spot where he was buried, so that when the railway should be completed the body could be removed.

Mr. Haslett was highly esteemed and respected by all who enjoyed his acquaintance; but those only who were admitted to his friendship knew his sterling worth as a Christian gentleman, his abhorrence of all that was mean or dishonourable, his modest estimation of self and of his high attainments, and his simple but earnest character. At the time of his death it is known that he was finishing a more comprehensive work on engineering than his "Field Book;" and it is to be hoped that this contribution to engineering literature, embracing as it no doubt does the results of his valuable and extended experience, will not be lost to the profession. He was elected an Associate of the Institution on the 23rd of May, 1865.

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Mr. THOMAS HOWARD was born in 1796, and was intended for the business of a manufacturing chemist. However, after acquiring considerable knowledge in the various departments of chemistry, his attention was turned more particularly to the chemistry of steam, especially with regard to its employment in the steam-engine. His first invention, in 1825, was a vapour-engine. This was soon superseded by an improved vapour-engine and condenser. The object of this invention was to dispense altogether with the then cumbrous boilers, by injecting water upon a heated surface, whereby sufficient steam was generated to supply each stroke of the engine. This was accomplished by fitting a number of wrought-iron cups into a plate, the lower portion of the cups dipping into mercury, and the plate beneath the mercury being heated by a fire. A large amount of evaporating surface was thus procured, and care was taken to superheat the steam, which was used expansively. Great difficulties were at first encountered in making the cups free from leakages; but afterwards the engine worked well, and great economy of fuel resulted. About that time tubular boilers came into use for marine purposes, and this, together with the difficulties attendant upon so great a novelty, caused the system, so far as the vaporizing was concerned, to be abandoned. In 1835 H.M.S. 'Comet,' which made one trip to Lisbon,

in 1836 the steam-vessel 'Vesta,' trading to Ramsgate and Margate, and in 1837 the 'Columbus,' built for Mr. Robert M'Calmont, of London, and intended to steam to America, were all fitted with these vaporizers, as well as with Mr. Howard's system of condensation, in which the water of condensation was taken through a system of thin tubes, with cold water constantly circulating outside, the area of surface being sufficient to cool the water for the purpose of re-injection. By this means the same water was employed again and again, and a pure supply insured for the boilers. The plan answered well, and has frequently been employed. In 1846 Mr. Howard adapted this improvement to ordinary steam-engines. In 1840 he joined the King and Queen Iron Works, Rotherhithe, with which members of his family had been connected for more than half a century. The work was a scrap-iron rolling-mill, and had a considerable reputation for the iron produced. A forge was now added, and from that period to the present time iron work of the heaviest descriptions used in marine and other engines has been manufactured there. In 1845, after a number of experiments, he succeeded in rolling at one heat the links with enlarged ends, for the suspension bridge at Pesth. The process mainly consisted of a combination of rolling transversely and endwise. Since then many large suspension-bridges have been completed with similar links: among them may be enumerated the Kieff Bridge, the Chelsea Bridge, and others of less importance; but by far the larger requirement for them has been in the construction of Warren girders. In 1857 Mr. Howard introduced some improvements, and in the details of the machinery made many experiments upon wrought iron. He was a careful investigator into its properties under varying circumstances, and frequently wrote to the scientific journals, his favourite subject being steam. He strongly advocated the use of superheating and expansion, stating as his opinion that half the fuel might be saved by the proper employment of these principles. He lived to see these improvements worked out, and producing the economies he anticipated; but, although one of the earliest experimenters upon some of the important changes lately perfected in the steam-engine, so long a period had elapsed since he was known in connection with them that his name is almost forgotten. He kept up a constant interest in the Iron Works, in which he remained the senior partner until the time of his death, which took place on the 13th of August, 1872.

Mr. Howard was elected an Associate of the Institution on the 24th of May, 1835. As an evidence of the interest he took in the Society, he bequeathed to it the sum of £500, free of legacy duty.

"to be invested, and the interest thereof to be applied in such manner and under such conditions and restrictions as the Council of the said Institution may think most expedient, for the purpose of presenting periodically a prize or medal to the Author of a treatise on any of the uses or properties of iron, or to the inventor of some new and valuable process relating thereto—such Author or inventor being a Member, Graduate, or Associate of the said Institution."

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Mr. ROBERT JOBSON was the eldest son of Robert and Janet Jobson, of Roscoe Place, Sheffield, where he was born on the 1st of April, 1817. His first introduction to business was in the year 1833, when he was articled to the late Mr. John Joseph Bramah, of Pimlico, London, who soon after that time became engaged in large contracts for iron bridges, and other engineering works, on the London and Birmingham, the Midland Counties, and afterwards on the North Midland and Birmingham and Derby railways. Mr. Jobson was intrusted with the carrying out and general superintendence of these contracts, and he executed them so satisfactorily that he was complimented thereon by the late Mr. Robert Stephenson, Past-President Inst. C.E. On the completion of these works Mr. Bramah transferred his business from London to the neighbourhood of Birmingham, and, having entered into partnership with Mr., afterwards Sir Charles, Fox and the late Mr. John Henderson, commenced the London works at Smethwick. About the same time Mr. Jobson entered into business upon his own account in the neighbourhood of Dudley, and executed the castings for various important works—amongst others, a large portion of those required for the Great Exhibition building of 1851, for the Crystal Palace, for the New Street Station at Birmingham, and for various other works.

His inventions were numerous, those best known being his moulding apparatus, and that for making compressed porcelain especially adapted for telegraph insulation.

He was elected an Associate of the Institution of Civil Engineers on the 21st of January, 1851, and he was also a Member of the Institution of Mechanical Engineers.

He was a magistrate for the borough of Dudley, and also an officer of the first battalion of Worcestershire Rifle Volunteers, from the time of its formation until his death, which took place suddenly, at his residence, Cotwall End House, near Dudley, on the 1st of August, 1872.

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Mr. WILLIAM LANG, the son of Mr. B. Lang, was born in Manchester in February, 1838. His education was obtained principally at Hawthorn Hall, Cheshire, under the tuition of Dr. Somerville, with whom he remained till 1856. He then entered the works of Messrs. Cochrane and Co., of Woodside, Dudley, and passed through the ordinary terms of probation in the several executive departments of the establishment, as well as in the drawing office. In the year 1861, before his pupilage had expired, Mr. Edwin Clark, M. Inst. C.E., had designed some additions to the Central Transept of the Crystal Palace, Sydenham, in order to strengthen the structure. Messrs. Cochrane and Co. were commissioned to carry them out, and Mr. Lang was intrusted by the firm with the supervision, first of the manufacture, and afterwards of the erection of the work. In 1862 Mr. Lang purposed to take advantage of the Civil Service appointments then newly thrown open for competition by examinations, for seeking a sphere of labour in India, but found he had just passed the limit of age. In 1863 the construction of the lock gates for the docks at Penarth, from the designs of Mr. Hawkshaw, Past-President Inst. C.E., was confided to the firm. The designs were placed in Mr. Lang's hands for working out the details, and on the completion of the manufacture of the gates he was further intrusted with the superintendence of their erection. Altogether this extensive work occupied him more than two years, and was his last engagement for Messrs. Cochrane. In the intervals of his professional employment subsequently, he extended his knowledge of engineering works both at home and abroad. He studied at the Royal School of Mines, attending the lectures of Professor Huxley and Dr. Percy, and he passed a year in Paris and on the Continent. He was elected an Associate of the Institution on the 5th of December, 1865, and was in a fair way to reap the fruits of steady and continuous labours in his profession, as a Civil Engineer in Manchester, when a termination was put to his career, which was almost tragic in its suddenness. He was never very strong, and had been crowding too much effort of mind and body into the short space of a few months before his marriage. The consequences appeared only when he had time for relaxation. He was seized with mortal illness during a wedding tour in the Isle of Wight, and died at Ventnor on the 28th of September, 1872. Mr. Lang had been married but a few days to Eliza, daughter of Mr. Edward Stone, of Burn Barton, Bickleigh, Devon. His friends have to regret the loss of a courteous and liberal-minded gentleman, who took a genial interest in the pur-

suits of others not connected with his own profession, and during seasons of leisure was able to bear his part well in the most vigorous and healthy forms of mental and physical recreation.

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Mr. FREDERICK MARRABLE, the eldest son of Sir Thomas Marrable, of St. James's Palace—Secretary to the Board of Green Cloth from January, 1830, to his death, on the 19th of March, 1850—was born on the 27th of April, 1818. He was educated by the celebrated Dr. Burney, of Greenwich, and served his articles with Mr. Edward Blore, architect for Westminster Abbey, and latterly for Buckingham Palace. In 1841 he commenced his professional career by taking chambers in Lancaster Place, Strand, and competing, though unsuccessfully, for the rebuilding of St. Giles's Church, Camberwell, the old edifice having been destroyed by fire. His next attempt was also unsuccessful, but owing to a different reason. Considering the then vacant ground opposite his windows an eligible site, the young architect made a clever design for a line of buildings to be called Lancaster Chambers, and applied for a lease of the ground. As, however, the completion of Somerset House was then in contemplation, this application was necessarily, and without disparagement it may be said, fortunately declined. Shortly afterwards he moved to Lincoln's Inn Fields, and, on the death of his father, to Rutland Gate. Here, in a locality not much suited to a person in his profession, he completed the drawings for the church of St. Mary Magdalene, Hastings, &c. In 1853 he visited Rome, Naples, Florence, &c. Early in the year 1856, the Metropolitan Board of Works having just been formed, he was elected to the office of Superintending Architect, an appointment which he held for five years, and which he resigned in 1861, not liking the restriction of being precluded from private practice. The favourable testimonials he received from the Chairman on that occasion showed how fully his services were appreciated by the Board. The current of Mr. Marrable's professional life was, however, to a considerable extent, changed by his connection with the Metropolitan Board of Works. In this position his practical knowledge and well-known integrity and independence were frequently brought to bear in a quasi-judicial position in a manner which did him great credit. The turn thus given to his mind, and the experience which he thus gained in dealing with large questions of property, found subsequent development in various arbitrations of importance, and in dealing with the purchase and

sale of property. In such practice the latter portion of his life was principally passed, and in this he attained an eminence well earned by the union of practical skill and unswerving uprightness. Mr. Marrable's works for public bodies are few in number. In addition to St. Mary Magdalene, before referred to, there may be mentioned St. Peter's Church, Deptford, the Garrick Club and adjoining buildings, the offices of the Metropolitan Board of Works in Spring Gardens, the Stockwell Fever Hospital, and Archbishop Tenison's School, in Leicester Square. He was also the author of one of the selected designs for the improvement of Holborn Valley, in 1863, which showed a considerable amount of architectural skill and picturesque treatment. He held the appointment of Surveyor to the Royal Hospitals of Bethlehem and Bridewell up to the time of his death, which occurred very suddenly, from a fit, while he was inspecting the works of the former hospital, at Witley, near Godalming, on the 22nd of June, 1872. Mr. Marrable married, on the 2nd of September, 1856, Madeline Frances Jane, eldest daughter of the late Mr. James Cockburn, of the Avenue Road. He was elected an Associate of the Institution on the 4th of March of the same year, and served on the Council in the session 1862–3.

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Mr. EDMUND MOREL, the only son of the late Mr. Thomas Morel, of Piccadilly and Notting Hill, was born on the 17th of November, 1841. He was educated at King's College, London, afterwards at technical schools in Germany and Paris, and subsequently studied at Woolwich for a commission in the Royal Engineers, which, however, his short sight disqualified him for. In May, 1858, he was articled to Mr. Edwin Clark, M. Inst. C.E., with whom he remained three years and a half. Leaving England, he served under the New Zealand Government, in 1862 and 1863, as Chief Assistant Road Engineer, and in the latter year was appointed Chief Engineer of the Province of Wellington. In 1864 and 1865 he was occupied with private practice, principally in Australia, and for the next year and a half in examining for a proposed railway in Labuan. In 1867 he was appointed Chief Engineer and manager for the Labuan Coal Company, to construct a railway, sink shafts, and open out mining arrangements. In 1869, his health breaking down, he proceeded to South Australia as Consulting Engineer to an association anxious to introduce the Indian guarantee system in that country. This

situation he resigned on being appointed Engineer-in-Chief for the laying out and making certain lines of railway, and for the designing, constructing, and carrying out of other public works in Japan. The engagement was for five years, and was concluded with Mr. Horatio Nelson Lay, C.B., who was invested with certain privileges by the Japanese Government, at Point de Galle. On arriving at Yokohama, on the 9th of April, 1870, he at once proceeded to set out a line of railway between Tokei and Yokohama, 20 miles in length; the works on this, and on another length of 20 miles, between Kobe and Otaka, were commenced under him, but he did not live to see their completion. Mr. Morel had for some months been in declining health, a constitutional weakness of the lungs having taken the form of rapid consumption, to which he succumbed on the 5th of November, 1871. His wife survived him only twelve hours; and they were buried together in the cemetery at Yokohama on Tuesday, the 7th of November, 1871. His services were highly appreciated by the Japanese Government. His Majesty the Temio, hearing of his illness, sent a letter of condolence by the Vice-Minister of Works, accompanied with a gift of £1,000, within a week of his death; and all the expenses of his funeral the Government offered to defray. Mr. Morel was a man of great energy and sterling integrity. His career had brought him into contact with classes of men who turned his profession into a trade, and tended to make it the instrument of injustice to governments and the public; to these he had an extreme antipathy. It was with a true estimate of his character and services that the Japanese Government, on withdrawing the powers of their commissioner, requested him to continue those services, and undertook the satisfaction of any penalty that might have been incurred by this act. He possessed that fineness of sensibility so commonly found among men of talent, nor was he free from that desire for distinction which, when unsatisfied, becomes a source of irritability. He plainly saw, as disease made ever greater inroads on his constitution, that this ambition could never be satisfied. But he never murmured against the dispensations of a Providence which he regarded as inscrutable but all-wise, and his high religious sense taught him that unquestioning submission to its decrees was his duty, and the best evidence he could give of his faith in the wisdom of those mysterious dispensations.

Mr. Morel was elected an Associate of the Institution on the 23rd of May, 1865.

Mr. AUGUSTUS SIEBE was born in Saxony in the year 1788, but was taken by his parents at an early age to Berlin, in which city he was educated. There he was apprenticed to a fine-caster, and early evinced great taste in modelling and chasing and in mechanical work. In 1812 he had to join the army, and fought as lieutenant in the artillery at the battle of Leipsic, where he was wounded. Peace being signed, he went to Kiel, and obtained a situation with a watch and clock manufacturer. In 1814 he came to England, and, while perfecting himself in the language, obtained employment in chasing, gun-making, &c. Eventually he became foreman and manager to an engineering firm, where his mechanical abilities brought him into note. At this period he invented a breech-loading rifle and a dial weighing-machine, and received a silver medal from the Society of Arts for improvements in taps. He eventually commenced business on his own account. As a proof of his efforts, it may be mentioned that several of the lathes and tools in his workshop were made by himself during his leisure hours at the time he was manager. He now invented a rotary pump, which brought his name before the engineering world, and his business rapidly increased. About 1829 he was introduced to Mr. A. Deane, who had invented an apparatus for entering into houses or buildings on fire, and suggested to him the practicability of working under water with a similar apparatus, and eventually constructed an air-pump and diving-dress, known as the open dress. With this apparatus much valuable property was recovered, and diving became a remunerative speculation. In 1837 he invented the close diving-helmet, which is hermetically fastened to the india-rubber dress, also the segmental neck-ring, by which the head-piece was removed from the collar by one-eighth of a turn. This helmet was further fitted with the inlet and outlet valve, and he also added the water apparatus to keep the cylinders cool, the pressure-gauge, &c. At this date the Royal Engineers commenced diving operations at the wreck of the 'Royal George;' and, at the request of the late Major-General Pasley, C.B. (then Colonel Pasley), he carried out a series of experiments with the Sappers and Miners; and the practical experience thus obtained led him to adopt the profession of a submarine engineer. He was appointed contractor to the Admiralty, his invention being used for the Navy and Dock Yards. He was also the manufacturer of the ice-making machinery.

For his various inventions he received prizes on the occasion of the Exhibitions—in London, in 1851; in Paris, 1855; London, 1862; and Dublin, in 1865. He carried on business up to his

eightieth year, when failing health induced him to retire in favour of his son and son-in-law.

Mr. Siebe was elected an Associate of the Institution on the 2nd of December, 1856. In manner he was retiring, kind of heart, and upright and honourable in his dealings. He died on the 15th of April, 1872, in his eighty-fourth year.

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Dr. GERRIT SIMONS was born at Thamen aan den Amstel, not far from Amsterdam, in 1802. He was the youngest son of Mr. Adam Simons, a popular poet, and a distinguished professor of Dutch literature, at the University of Utrecht. At the age of seventeen Mr. Gerrit Simons attended the courses of lectures on medicine at that university; but some time afterwards his personal preference for the science of geometry and natural philosophy induced him to discontinue them. In the new branch of science to which he devoted himself he began very early to show superior attainments; and, while yet a student, he was awarded a gold medal for a Paper upon the chemical composition of aqueous vapour in the atmosphere. About the same time he was appointed Observer at the Observatory of Utrecht. After having published a dissertation upon the expansion of liquids by heat, he received the degree, in 1828, of Doctor of Philosophy. Two years later his scientific researches were stopped for some time in consequence of political events; and he served as a volunteer in the civic guards during the war with Belgium. In 1832 he was appointed Consulting Chemist and Mechanician to the Ministry of the Interior at the Hague. During a residence of about thirteen years there Mr. Simons distinguished himself by a series of useful labours.

In 1838 he was appointed a member of the committee nominated for reporting upon the best means of draining the lake called Haarlemmermeer, with an area of about 45,000 acres; and he prepared a valuable memoir upon the subject, which was published and presented to the King in 1839. In those days it was a question whether the motor to be adopted for the pumping machinery should be wind or steam. Very many water-mills, driven by the action of the wind, were in existence, while steam-mills were almost unknown. A few experiments with steam-mills had given no favourable results, when looked at from an economical point of view. In the designs for the drainage of the Haarlemmermeer, made in 1838, a combination of seventy-

nine wind-mills and three steam-mills of 40 H.P. each were proposed. Mr. Simons, however, demonstrated that great improvements could be introduced in the existing steam-mills, and that for a lake of this large size powerful steam-pumps were the most appropriate. The question was decided in 1840 in accordance with that opinion; and three large pumping-engines were erected, which, in honour of three great promoters of the drainage, were called Leeghwater, Cruquius, and Lynden. The Leeghwater has eleven pumps, each 1·60 mètre in diameter; both the other engines have eight pumps, of 1·83 mètre diameter. The average depth from which the water is pumped is 4·5 mètres. The pumps can work combined or separately. During the whole of the drainage operations eight or nine pumps of the Leeghwater, and six or seven pumps of the two other engines were, on the average, at work. The pumping was completed in three years and seven months, in which time about 832,000,000 cubic mètres of water were pumped out. The total cost of the enterprise was about £700,000. The drainage has proved a complete success; a stormy and dangerous lake has been replaced by a fertile *polder;* and a numerous population earn their living from the drained soil. During the whole period of the execution of these works Mr. Simons took an active part in designing the machinery. In 1840 he was nominated a member of the Committee of Government Superintendents; and he paid repeated visits to English engine-works, particularly to those of Messrs. Harvey and Co., and Messrs. Fox and Co. in Cornwall, and of Messrs. Gibbs and Dean of London, who had undertaken part of the designing and of the construction of the engines. His special study of the advantages to be obtained by the application of steam in drainage-works procured him a Gold Medal, in 1844, for a Paper written in conjunction with the late Chief Engineer of the Waterstaat, A. Greve, and awarded by the Academy of Science at Rotterdam. Seven years later, he was once more called upon to give proof of his ability in this branch of engineering, when he was appointed a member of the committee nominated for reporting upon the proposed drainage of a bay along the North Sea, called the Lauwerzeer, in the province of Friesland.

In the following year a new sphere of activity was opened to Mr. Simons. He was appointed at first Deputy-director, and shortly afterwards Director, of the Royal Academy of Civil Engineers, which was founded at that time at Delft. He kept that position till 1856, and his earnest, liberal, and genial directorship secured him the high approbation of the Government, and the general esteem and sympathy of the scholars. It was a great loss for the

engineering school, when Mr. Simons accepted a seat in the Cabinet, in 1858. He was appointed Minister for the Interior; but though his activity was beyond praise he was not supported by a majority in the Second Chamber; and when, a few months after, the yearly budget was rejected, Mr. Simons resigned the post, in order to recover his health, which was seriously affected. On this occasion the King of the Netherlands gave him a flattering proof of interest and good-will by putting a part of the royal castle, "Het Loo," at the disposal of the patient.

Mr. Simons, having quite recovered his health, was able to accept a place in the Council of State. He held this post till 1862, when, on a reorganization of the Council, the honorary membership was presented to him. About this time he was elected a member of the Second Chamber Parliament for the township of Gorinchem, a position he retained till 1868, when a serious illness proved fatal to his noble and useful life.

During his stay at the Hague he was one of the editors of a scientific periodical, in which several articles from his pen give a proof of his witty and keen critical talent. Wishing to contribute to the best of his ability in rendering the knowledge of natural philosophy and applied mechanics more general and popular, he commenced a course of lectures in 1835. These were attended by a numerous audience; and he continued them every winter till 1840, being assisted during the latter part of that period by his friend, Dr. A. Vrolik. In 1846 he was one of the three founders of the Royal Institute of Civil Engineers in Holland; the late Mr. F. W. Conrad, M. Inst. C.E., being another. In the same year Mr. Simons was appointed Member of Council of the Society for promoting the Development of Industry; and during seventeen years acted in that capacity with great zeal and energy. He gave the impulse, or at least contributed largely, to the organization of the exhibitions at Delft, in 1849, and at Haarlem, in 1861. An eloquent plea, in favour of getting the labour of children in factories settled by law, was presented by the above-mentioned Society to the King of the Netherlands, of which every line bore the character of Mr. Simons' style. A report upon the desirability of abolishing the grants, or patents, was written by him in 1854. The Royal Academy of Science at Amsterdam presented him with their diploma of membership; and in 1857 he was elected a President of the section of Natural Philosophy. The King of Holland presented him with the Order of the Dutch Lion, and with that of the Royal Oak of Luxemburg. The Emperor of Russia offered him the decoration of St. Anne. He was elected an Associate of the Insti-

tution of Civil Engineers on the 15th of June, 1841. Mr. Simons died at the Hague on the 17th of November, 1868. At the cemetery of Eik en Duinen, close to the residence, a simple monument shows the place where his body reposes. The words of Horace, "Integer vitæ," which are engraved on his tomb-stone, have rarely been more deservedly applied.

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Mr. WILLIAM SYKES was born at Cortworth, near Wentworth, Yorkshire, on the 27th of September, 1815. He was apprenticed at an early age to his uncle, who was master-builder for Earl Fitzwilliam, engaged in building and colliery works. When not much more than twenty years of age he took a contract on the Midland railway, and in the year 1839 he built a station, engine-house, and workshops at Bromsgrove, on the Birmingham and Gloucester railway. In the year 1840 he tendered for works on the River Shannon, and in partnership with his cousin, Mr. John Brookfield (late of Halifax, Nova Scotia), built two large bridges—one at Lanesborough, Co. Longford, the other at Tarmonberry, Co. Roscommon;—and the same firm also deepened the River Shannon by dredging. In 1846 Mr. Sykes went to Scotland, and, in partnership with Mr. Wardrop, constructed a large portion of the railway between Dumfries and Glasgow. After seven years' residence there he proceeded to Nova Scotia to make surveys for the projected railway system of that province, and, returning to England, sailed to Canada as one of the firm of Sykes, De Bergue, and Co., contractors for the Brockville and Ottawa and Montreal and Bytown railways, the whole of the preliminary works of which were carried out under his direction and supervision. Financial difficulties supervening, on the occasion of the Crimean war, the works were suspended, and Mr. Sykes removed to Upper Canada. There he matured the plan of a new system of tunnelling under rivers. Mr. Sykes designed and executed the preliminary plans for a ship-canal to unite lakes Huron and Ontario, debouching on the latter at Toronto. He was also engaged as engineer on the Port Perry and Whitby railway, and as contractor on the Canada Southern railway, where exposure during the severe weather of winter brought on the disease that ultimately resulted in his death, which took place on the 3rd of April, 1872.

Mr. Sykes was elected an Associate of the Institution on the 7th of April, 1868. He was of a singularly modest disposition, and was much endeared to a large circle of friends and acquaintances for his amiable, honourable, and upright character.

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Mr. ROBERT HARRY INGLIS SYNNOT was born at Clapham in 1837, and was educated at Harrow, and at Christ Church, Oxford, where he graduated M.A. in 1860. In the same year, having a natural taste for engineering pursuits, he articled himself to Mr. Shelley, Assoc. Inst. C.E. After the termination of his pupilage, in November, 1863, he continued for a short time to assist Mr. Thos. Ormiston, M. Inst. C.E., Resident Engineer on behalf of Messrs. Lee and Sons, the contractors for the Plymouth Breakwater, with whom the latter part of his time had been spent. He subsequently became Resident Engineer on the Wrexham, Mold, and Connah's Quay railway, and, under Mr. T. C. Watson, M. Inst. C.E., assisted Messrs. Lee and Sons in carrying out the Amsterdam Sea Canal works. At the commencement of the year 1872 the desire for more constant employment than the profession at that time afforded led him to embark in the timber trade; but he had scarcely done so when he was seized with an attack of rheumatic fever, which in less than three weeks proved fatal. He died in London, on the 12th of April, 1872, having been an Associate of the Institution since February the 2nd, 1864.

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Mr. ARTHUR VALENTINE was born at King's Heath, near Birmingham, in the year 1839. He was educated at the Birmingham Grammar School, and afterwards was articled to Mr. D. G. Henry, then Borough Surveyor of Wolverhampton. After leaving Mr. Henry, he was for a short time engaged under Mr. Hughes, the Gas Engineer. In 1861 he became Resident Engineer upon the Lynn and Hunstanton railway, then about to be constructed under the direction of his cousin, Mr. John S. Valentine, M. Inst. C.E.; and upon the completion of this railway he held the same appointment, under Mr. John S. Valentine, on the West Norfolk Junction railway. These two railways, the one 15 miles the other 18 miles in length, were executed under his superintendence. He was also employed, under his cousin, upon the works which he constructed upon the Marshland drain for the Court of Sewers for the county of Norfolk, at the time of the destruction of the Middle Level and the Marshland Smee and Fen Sluices.

In October, 1868, he obtained an appointment as Assistant-Engineer in the service of the Indian Government; and he died at Lucknow, after a very short illness, on the 14th of May, 1872, in the thirty-third year of his age. Mr. Valentine was elected an Associate of the Institution on the 1st of March, 1864.

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END OF VOL. XXXVI.

1939

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